PASC19-MiniSymposia Session VI

Friday 14.06

Computational Performance Evaluation for Hardware and Software Alternatives to increase the HPC efficiency of Earth System Models

Organizers: Mario Acosta (Barcelona Supercomputing Center) and Tim Whitcomb (U.S. Naval Research Laboratory)

Presentations:

10:30 - 11:00	New Methodologies for Computational Performance Evaluation of Climate and Weather Models
	Authors: Mario Acosta, Miguel Castrillo, Stella Paronuzzi, Kim Serradell, Oriol Tinto, Xavier Yepes
11:00 - 11:30	Improving Ocean Model Computational Performance by using Mixed-Precision Approaches
	Authors: Oriol Tinto, Mario C. Acosta, Miguel Castrillo, Kim Serradell, Francisco Doblas-Reyes
11:30 - 12:00	Reduced Numerical Precision in Atmosphere Models and Computational Performance Evaluation
	Authors: Peter Dueben, Mario Acosta
12:00 - 12:30	Evaluating Commercial Distributed Computing for Numerical Weather Prediction
	Authors: Tim Whitcomb, Daniel Arevalo

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EXCELENCIA SEVERO OCHOA

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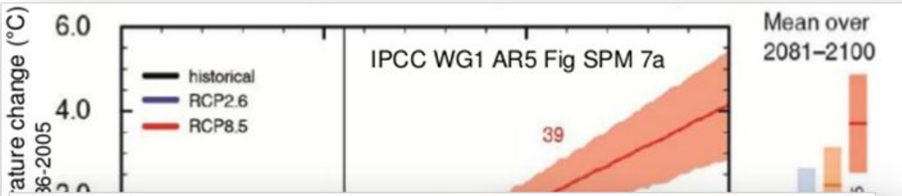
New Methodologies for Computational Performance Evaluation of Climate and Weather Models

Mario C. Acosta, Oriol Tintó, Miguel Castrillo, Stella Paronuzzi, Xavier Yepes and Kim Serradell

14/06/2019

PASC19 Zurich - Minisymposia 06

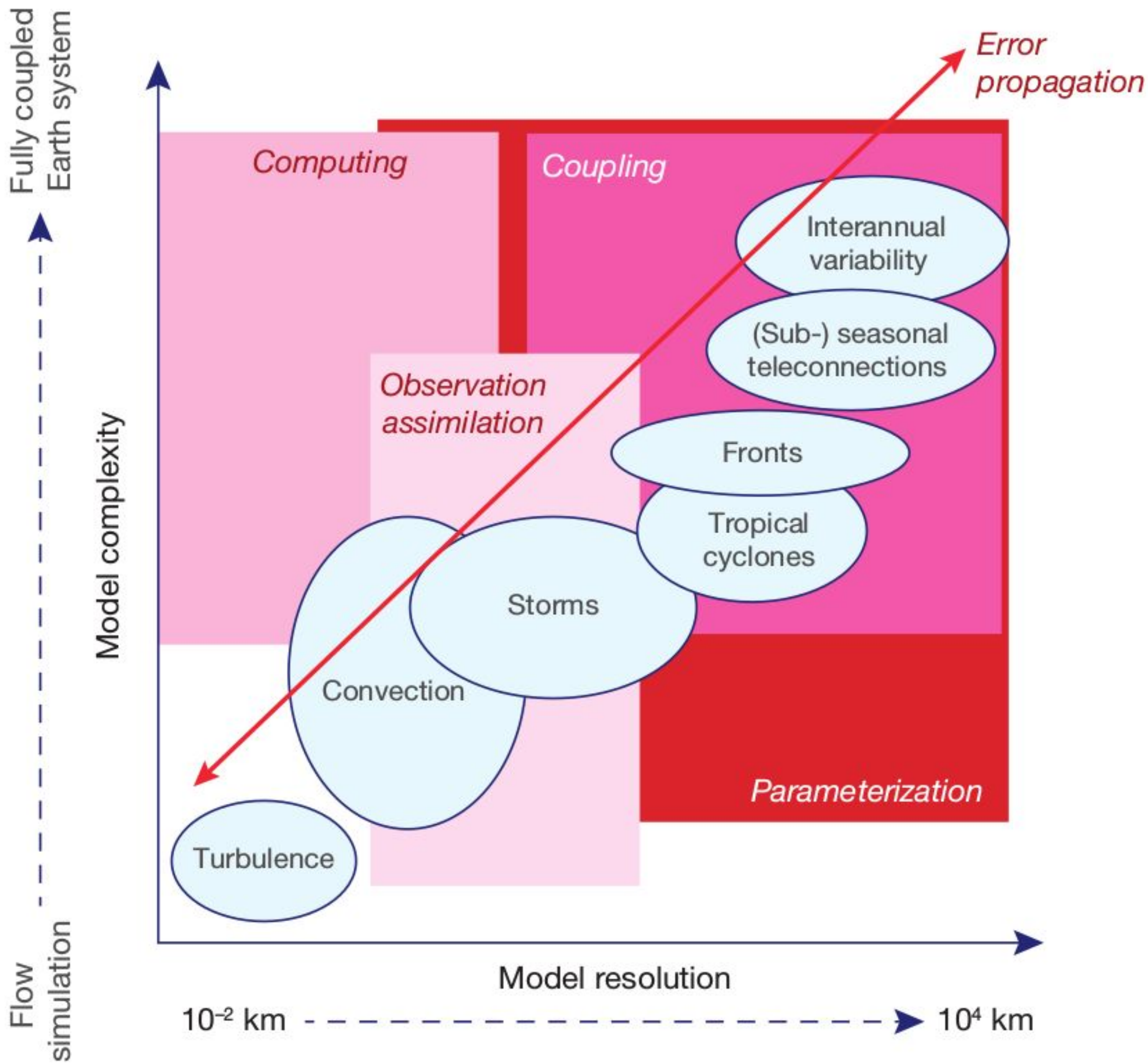
Introduction



- Projections
- Impact analysis
- Adaptation to climate change.

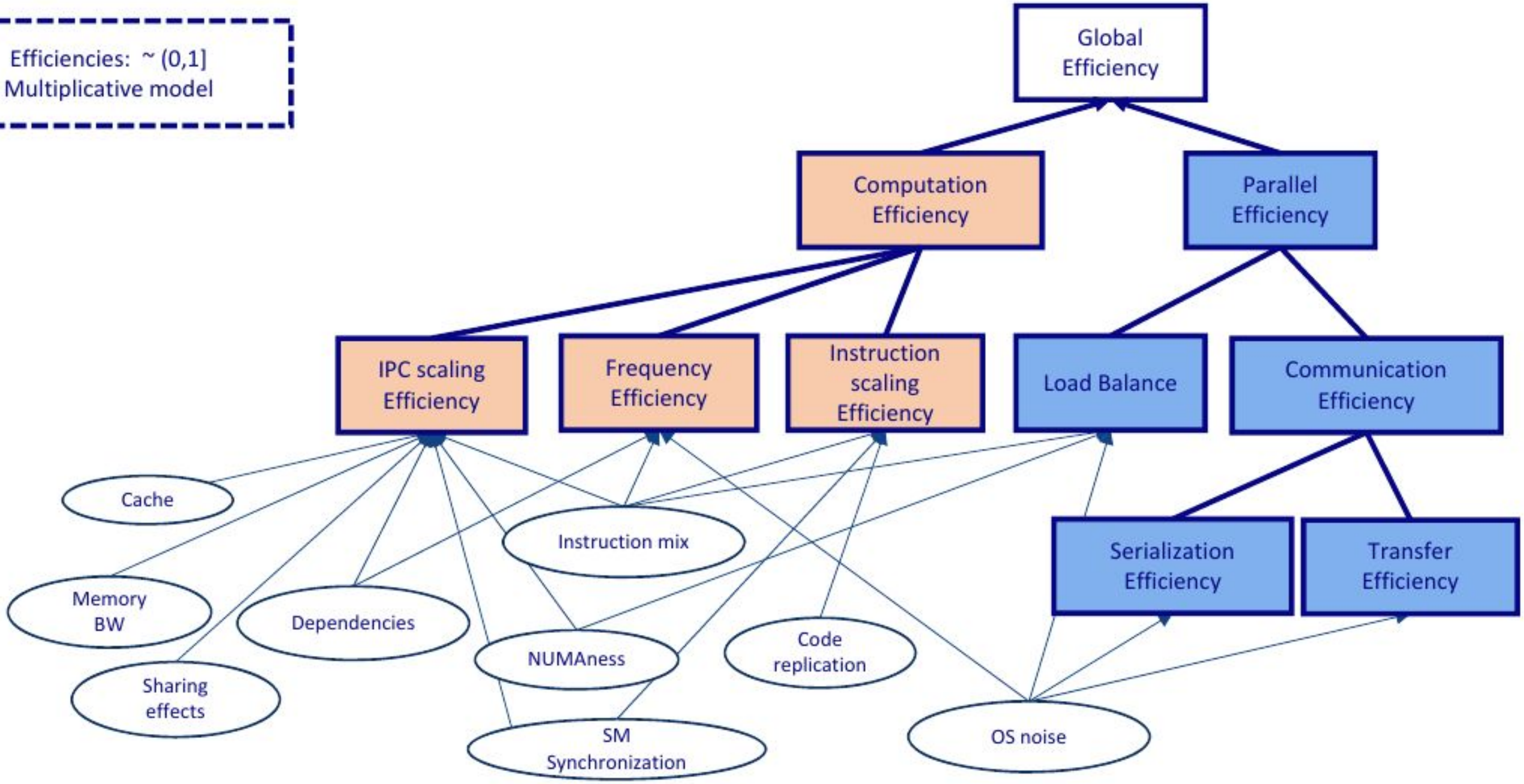
Currently, **only computational models have the potential** to provide geographically and physically consistent estimates.

Introduction



Introduction

Efficiencies: ~ (0,1]
Multiplicative model



Introduction

- The necessary refactoring of numerical codes is given a lot of attention and is stirring a number of discussions.
  - Computational performance analysis and new optimizations are needed for actual numerical models.
  - Study new algorithms for the new generation of high performance platforms (path to exascale).
- Several European institutions and projects working together on the same direction (ESCAPE2, ESiWACE2, IS-ENES3, ETP4HPC…)

Profiling Methodology

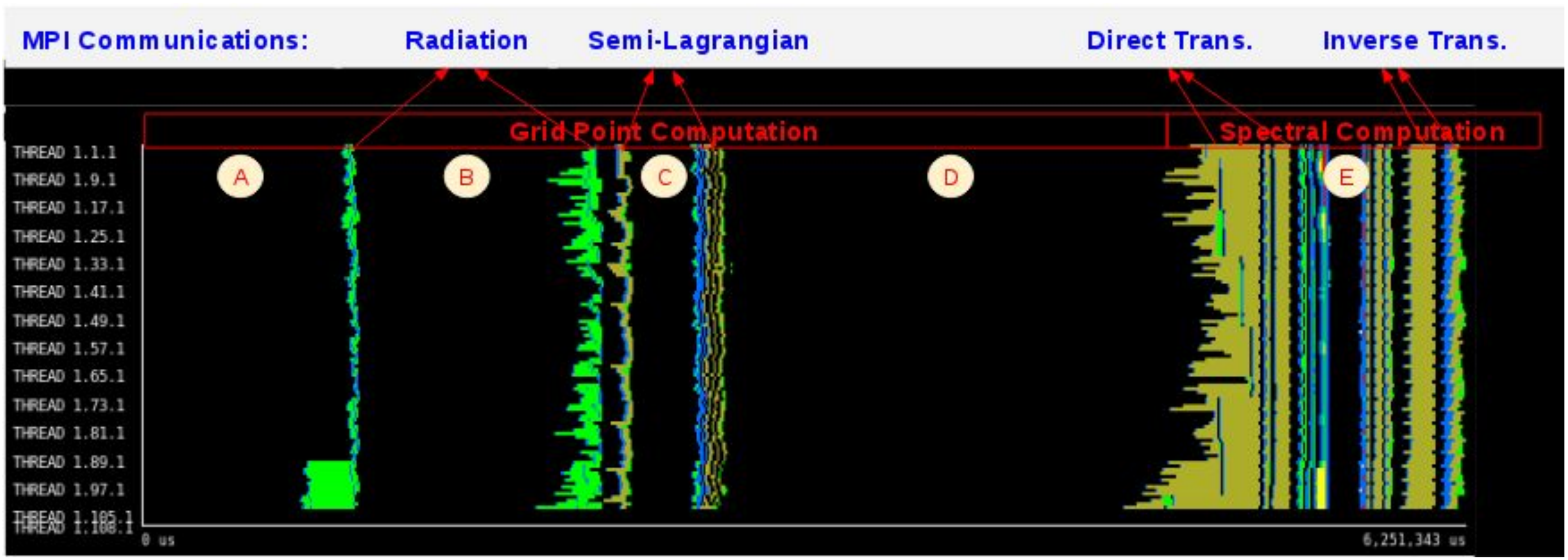
- Area of study
- Deployment efficiency
- Benchmarking
- Profiling analysis
- Validation

Profiling Methodology

- **Area of study**
  - Configuration used (Operational, New algorithms, Global, Parallelization paradigm…)
  - Components activated and cyclic patterns
    - IO, ICE, Radiation, MPI, OpenMP
  - Area of study
    - 1 complete time step
- Deployment efficiency
- Benchmarking
- Profiling analysis
- Validation

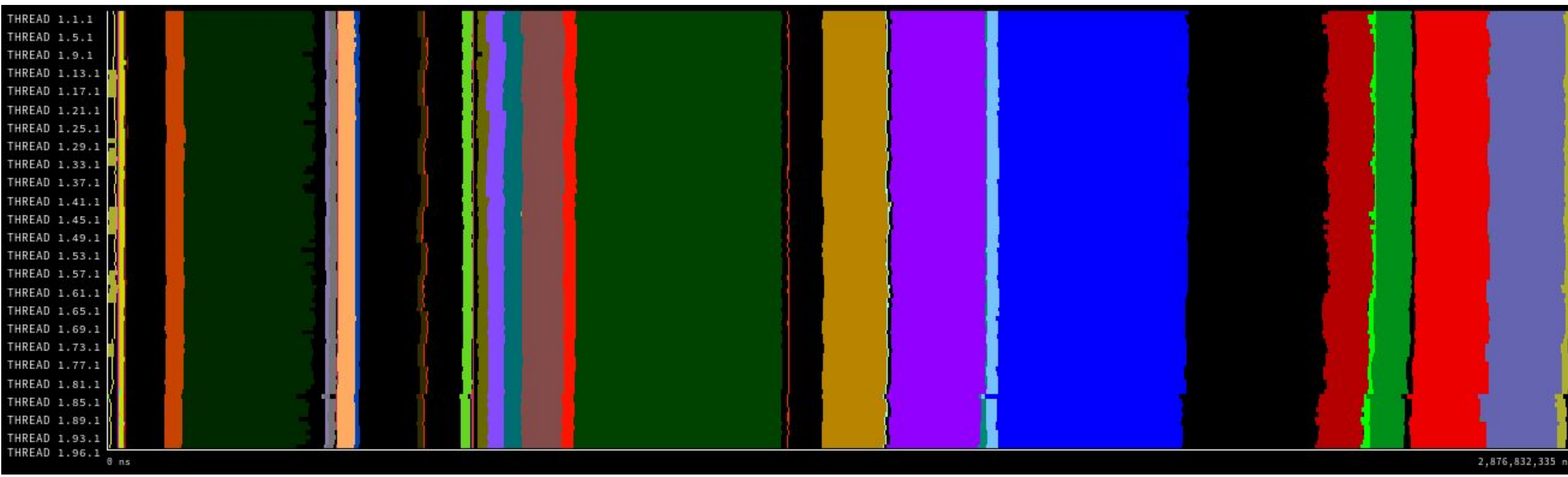
Profiling Methodology

- Area of study (IFS)
  - 24 hours of simulation, T511L137 on CCA (ECMWF)
  - Selected 1 time step: 104 MPI processes + 4 IO (No OpenMP)
  - Metrics collected for large areas of computation automatically

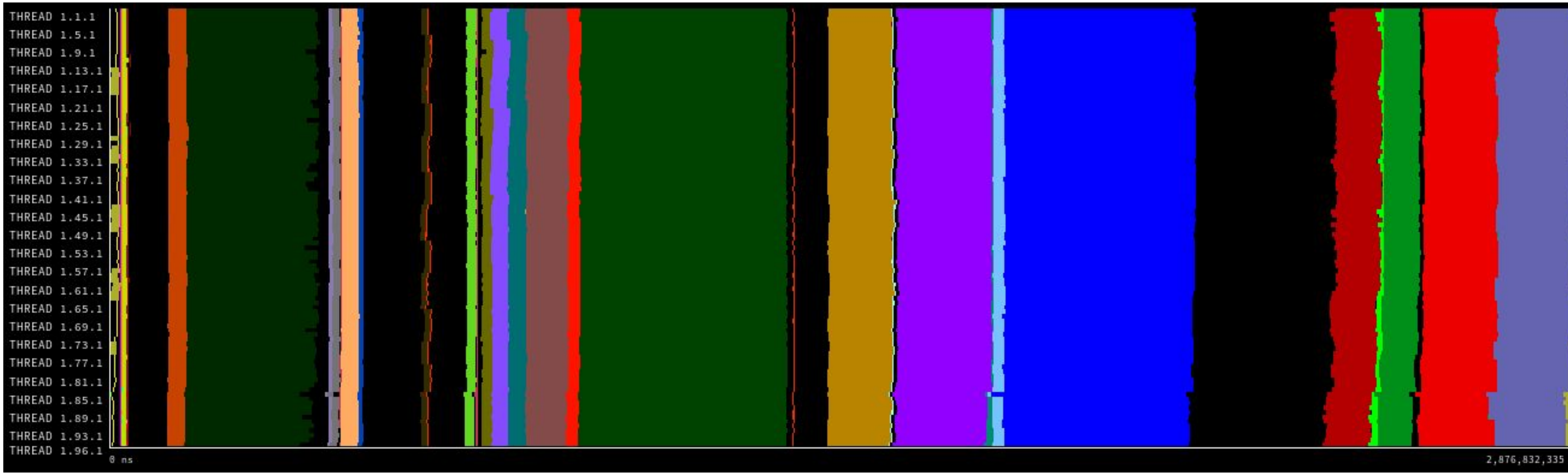


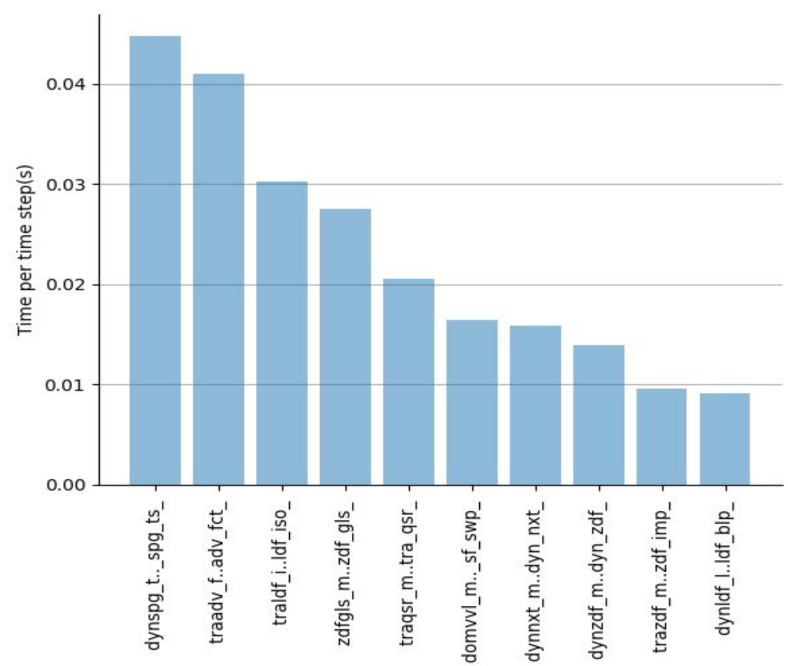
Profiling Methodology

- Area of study (NEMO)
  - 1 day of simulation, ORCA025L91 on MN4 (BSC)
  - Selected the fastest time step automatically
  - 1 time step: 72 MPI processes (No IO, No OpenMP, No SI3)
  - Metrics collected for User functions manually



Profiling Methodology





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Profiling Methodology

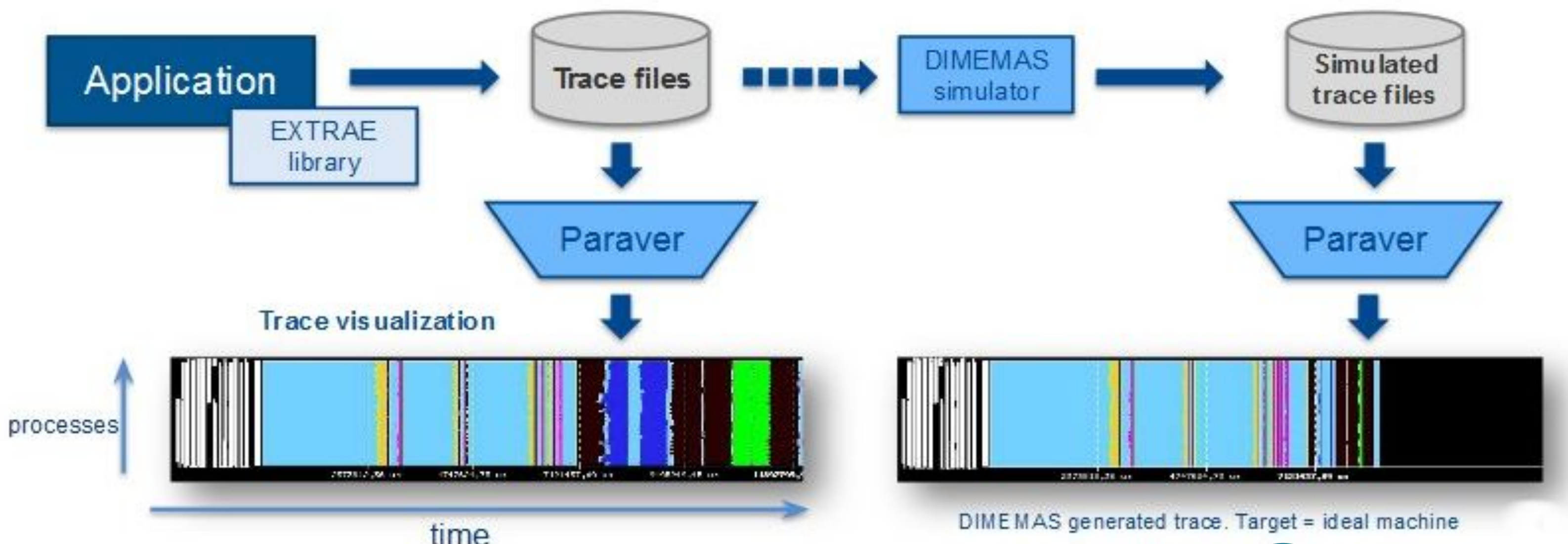
- Area of study
- **Deployment efficiency**
  - Compilation flags
    - Comparing fp options (fast, precise, strict...) and optimization options (OX, vectorization, approximations...)
  - Checking external libraries compilation
  - Debug flags (-g, Optimization reports, -f-instrument-functions...)
- Benchmarking
- Profiling analysis
- Validation

Profiling Methodology

- Area of study
- Deployment efficiency
- **Benchmarking**
  - Basic Tests to collect Hardware metrics
    - Communications (Latency, Bandwidth, CPU, Parallel Efficiency…)
  - Weak and Strong scaling (MPI, OpenMP, Block processing and Hybrid sets)
  - Comparing optimizations (Double VS Single Precision...)
  - Extrae metrics collection and trace production
- Profiling analysis
- Validation

BSC Tools

- Since 1991
- Based on traces
- Open Source → http://www.bsc.es/paraver
- Extrae: Package that generates Paraver-trace files for a post-morten analysis
- Paraver: Trace visualization and analysis browser
- Dimemas: Message passing simulator
- Include traces manipulation: Filter, cut traces...



BSC Tools

CORE TOOLS

EXTRAE
Instrumentation framework to generate execution traces of the most used parallel runtimes.

Get EXTRAE

Version 3.4.3 • 2.32 MB

PARAVER
Expressive powerful and flexible trace visualizer for post-mortem trace analysis.

Get PARAVER

Version 4.6.3 • 1.56 MB

DIMEMAS
High-abstracted network simulator for message-passing programs.

Get DIMEMAS

Version 5.3.0 • 0.93 MB

PERFORMANCE ANALYTICS

CLUSTERING
Automatically expose the main performance trends in applications' computation structure.

Get CLUSTERING

Version 2.6.6 • 1.97 MB

TRACKING
Analyze how the behavior of a parallel application evolves through different scenarios.

Get TRACKING

Version 2.6.5 • 1.88 MB

FOLDING
Combined instrumentation and sampling for instantaneous metric evolution with low overhead.

Get FOLDING

Version 1.3.1 • 12.67 MB

SPECTRAL
Signal processing techniques to select representative regions from Paraver traces.

Get SPECTRAL

Version 3.4.0 • 0.3 MB

BASIC ANALYSIS
Framework for automatic extraction of fundamental factors for Paraver traces.

Get BASIC ANALYSIS

Version 0.2 • 66.41 MB

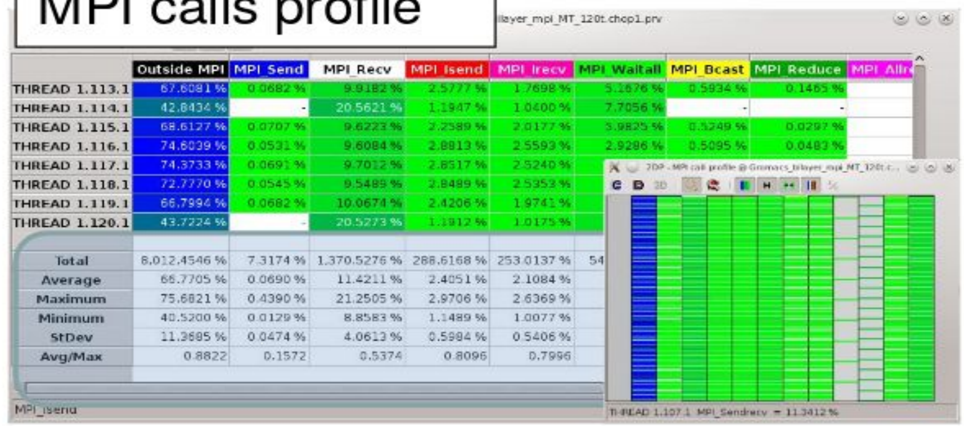
https://tools.bsc.es/downloads

BSC Tools

- From timelines to tables

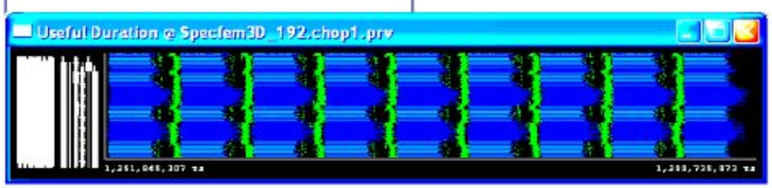
MPI calls

MPI calls profile

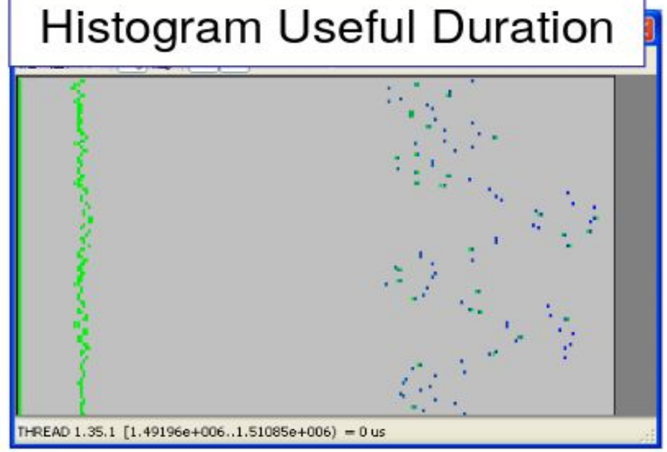


	Outside MPI	MPI_Send	MPI_Recv	MPI_Isend	MPI_Irecv	MPI_Waitall	MPI_Bcast	MPI_Reduce	MPI_Allr
THREAD 1.113.1	67.6081 %	0.0682 %	9.9182 %	2.5777 %	1.7698 %	5.1676 %	0.5934 %	0.1465 %	
THREAD 1.114.1	42.8434 %	-	20.5621 %	1.1947 %	1.0400 %	7.7056 %	-	-	
THREAD 1.115.1	68.6127 %	0.0707 %	9.6223 %	2.2589 %	2.0177 %	5.9825 %	0.5249 %	0.0297 %	
THREAD 1.116.1	74.6039 %	0.0531 %	9.6084 %	2.8813 %	2.5593 %	2.9286 %	0.5095 %	0.0483 %	
THREAD 1.117.1	74.3733 %	0.0691 %	9.7012 %	2.8517 %	2.5240 %				
THREAD 1.118.1	72.7770 %	0.0545 %	9.5489 %	2.8489 %	2.5353 %				
THREAD 1.119.1	66.7994 %	0.0682 %	10.0674 %	2.4206 %	1.9741 %				
THREAD 1.120.1	43.7224 %	-	20.5273 %	1.1912 %	1.0175 %				
Total	8,012.4546 %	7.3174 %	1,370.5276 %	288.6168 %	253.0137 %	54			
Average	66.7705 %	0.0690 %	11.4211 %	2.4051 %	2.1084 %				
Maximum	75.6821 %	0.4390 %	21.2505 %	2.9706 %	2.6369 %				
Minimum	40.5200 %	0.0129 %	8.8583 %	1.1489 %	1.0077 %				
StDev	11.3685 %	0.0474 %	4.0613 %	0.5984 %	0.5406 %				
Avg/Max	0.8822	0.1572	0.5374	0.8096	0.7996				

Useful Duration

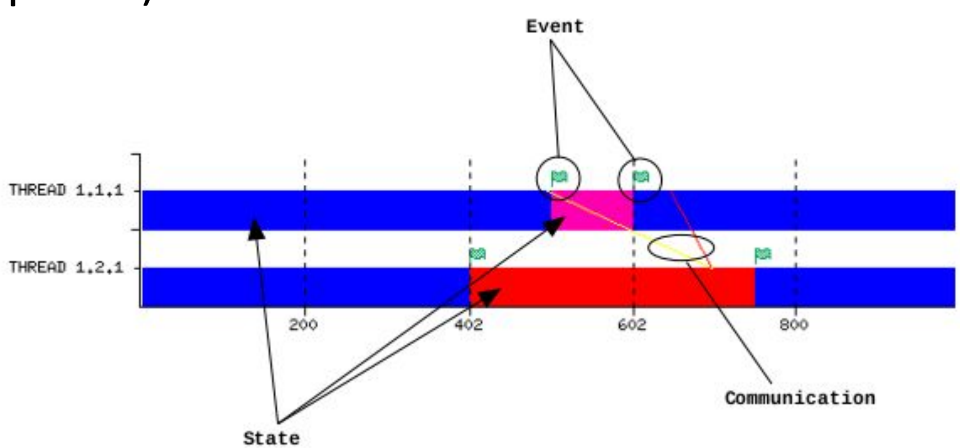


Histogram Useful Duration



BSC Tools

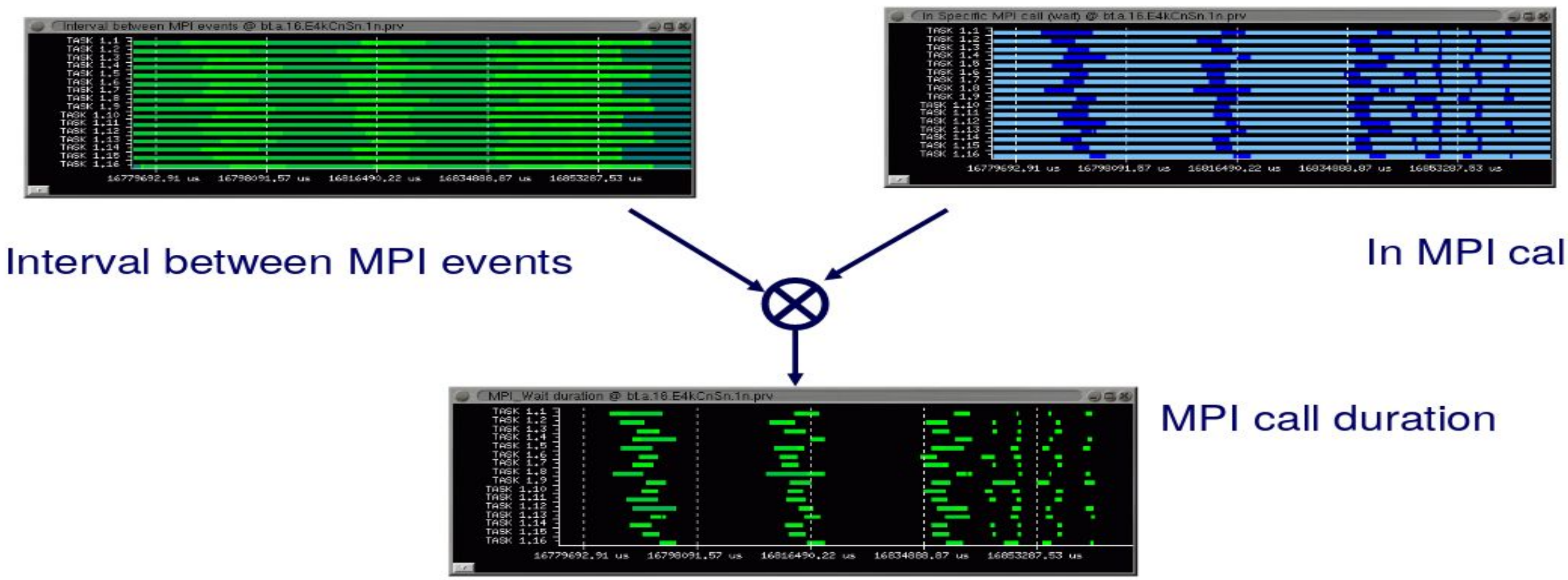
- Paraver traces: made up from records (timestamp + event or activity) of three different kind:
  - State records: intervals of thread status, i.e, waiting in a barrier (either MPI or OpenMP), waiting for a message, computing…
  - Event records: punctual event occurred in a given timestamp, as entry & exit points of user functions, MPI routines, OpenMP parallel regions…
  - Communication records: relationship between two objects, as communication between two processes (MPI), task movement among threads (OpenMP/OmpSs) or memory transfers (CUDA/OpenCL).



BSC Tools

Semantic Funcionality

- Derived windows
  - Point wise operation
    - $S = \alpha * S^a \langle op \rangle \ \beta * S^b$
    - <op> : + , -, *, /, …



Profiling Methodology

- Area of study
- Deployment efficiency
- Benchmarking
- **Profiling analysis**
  - MPI and OpenMP profile summary and Basic Analysis Tool
  - PAPI counters
  - MPI and OpenMP evaluation in detail
  - Clustering and Tracking Tools
  - Sampling and Folding Tools
  - Connection to the code
  - Dimemas Tool
- Validation

MPI Profile Summary

Parallel and Communication efficiency, Global load balance → less than 85%?

Parallel Efficiency

IFS

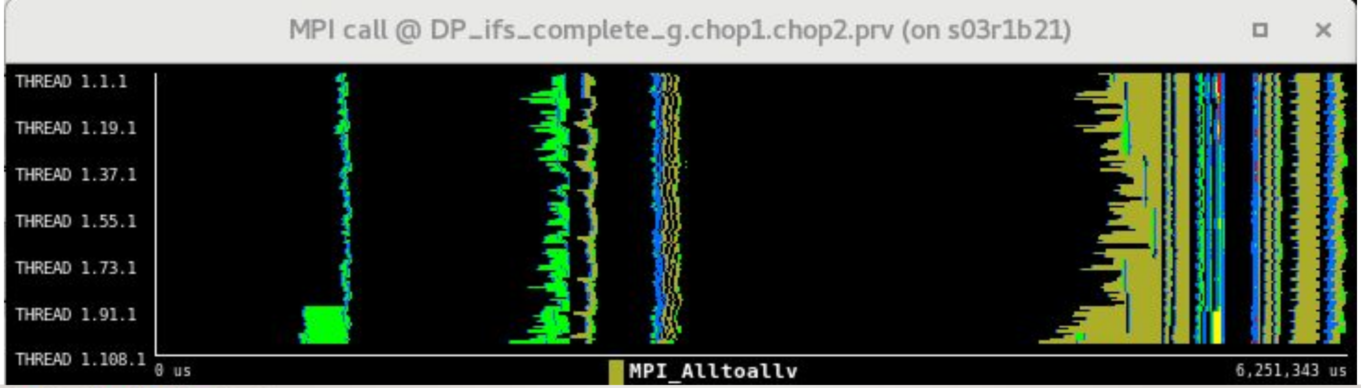
	Outside MPI	MPI_Send	MPI_Recv	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Barrier	MPI_Alltoallv	MPI_Gatherv	MPI_Comm_rank	MPI_Comm_size	MPI_Bsend	MPI_Waitany
Total	66,578.44 %	1.71 %	773.76 %	646.21 %	239.35 %	12,362.37 %	806.93 %	10,757.31 %	35.56 %	2.49 %	448.23 %	0.81 %	7,746.82 %
Average	66.31 %	0.00 %	0.77 %	0.64 %	0.24 %	12.31 %	0.80 %	10.71 %	0.04 %	0.00 %	0.45 %	0.81 %	7.72 %
Maximum	72.93 %	0.01 %	2.98 %	1.60 %	0.80 %	18.56 %	1.84 %	25.06 %	1.12 %	0.01 %	1.88 %	0.81 %	19.25 %
Minimum	57.05 %	0.00 %	0.01 %	0.08 %	0.07 %	3.11 %	0.00 %	5.25 %	0.00 %	0.00 %	0.16 %	0.81 %	0.31 %
StDev	2.03 %	0.00 %	0.57 %	0.36 %	0.06 %	2.52 %	0.41 %	3.57 %	0.12 %	0.00 %	0.10 %	0 %	3.18 %
Avg/Max	0.91	0.31	0.26	0.40	0.30	0.66	0.44	0.43	0.03	0.34	0.24	1	0.40

MPI_Send

Communication Efficiency

Global Load Balance

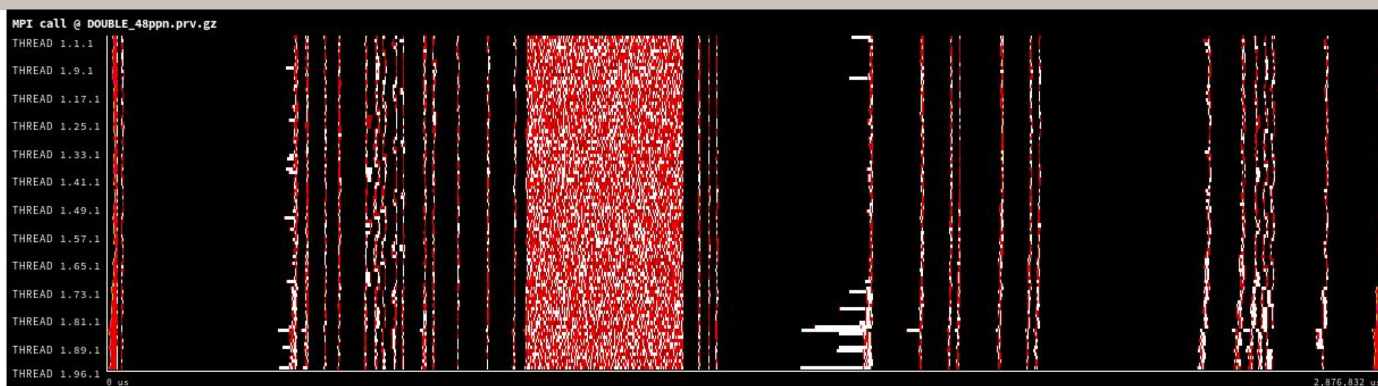
IFS



	Outside MPI	MPI_Send	MPI_Recv	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Barrier	MPI_Alltoallv	MPI_Gatherv	MPI_Comm_rank	MPI_Comm_size	MPI_Bsend	MPI_Waitany
Total	66,578.44 %	1.71 %	773.76 %	646.21 %	239.35 %	12,362.37 %	806.93 %	10,757.31 %	35.56 %	2.49 %	448.23 %	0.81 %	7,746.82 %
Average	66.31 %	0.00 %	0.77 %	0.64 %	0.24 %	12.31 %	0.80 %	10.71 %	0.04 %	0.00 %	0.45 %	0.81 %	7.72 %
Maximum	72.93 %	0.01 %	2.98 %	1.60 %	0.80 %	18.56 %	1.84 %	25.06 %	1.12 %	0.01 %	1.88 %	0.81 %	19.25 %
Minimum	57.05 %	0.00 %	0.01 %	0.08 %	0.07 %	3.11 %	0.00 %	5.25 %	0.00 %	0.00 %	0.16 %	0.81 %	0.31 %
StDev	2.03 %	0.00 %	0.57 %	0.36 %	0.06 %	2.52 %	0.41 %	3.57 %	0.12 %	0.00 %	0.10 %	0 %	3.18 %
Avg/Max	0.91	0.31	0.26	0.40	0.30	0.66	0.44	0.43	0.03	0.34	0.24	1	0.40

MPI_Send

NEMO



	Outside MPI	MPI_Recv	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Barrier	MPI_Issend	MPI_Test	MPI_Iprobe
Total	9,047.79 %	434.54 %	38.68 %	0.03 %	38.73 %	40.14 %	0.06 %	0.01 %	0.01 %
Average	94.25 %	4.53 %	0.40 %	0.00 %	0.40 %	0.42 %	0.00 %	0.00 %	0.00 %
Maximum	95.86 %	13.65 %	0.54 %	0.00 %	1.04 %	1.39 %	0.00 %	0.00 %	0.00 %
Minimum	84.07 %	2.77 %	0.28 %	0.00 %	0.12 %	0.11 %	0.00 %	0.00 %	0.00 %
StDev	1.94 %	1.74 %	0.06 %	0.00 %	0.21 %	0.32 %	0.00 %	0.00 %	0.00 %
Avg/Max	0.98	0.33	0.75	0.38	0.39	0.30	0.59	0.24	0.33

Basic Analysis

Overview of the collected raw data:

	108	108
Runtime (us)	110741508.76	71238767.9
Runtime (ideal)	105675625.64	68396939.23
Useful duration (average)	88427932.03	57382830.24
Useful duration (maximum)	94410288.2	61484222.58
Useful duration (total)	9196504931.3	5967814345.21
Useful duration (ideal, max)	94410288.2	61484222.58
Useful instructions (total)	26798422515714	23201423473963
Useful cycles (total)	21985000332874	14299301515415

Overview of the computed model factors:

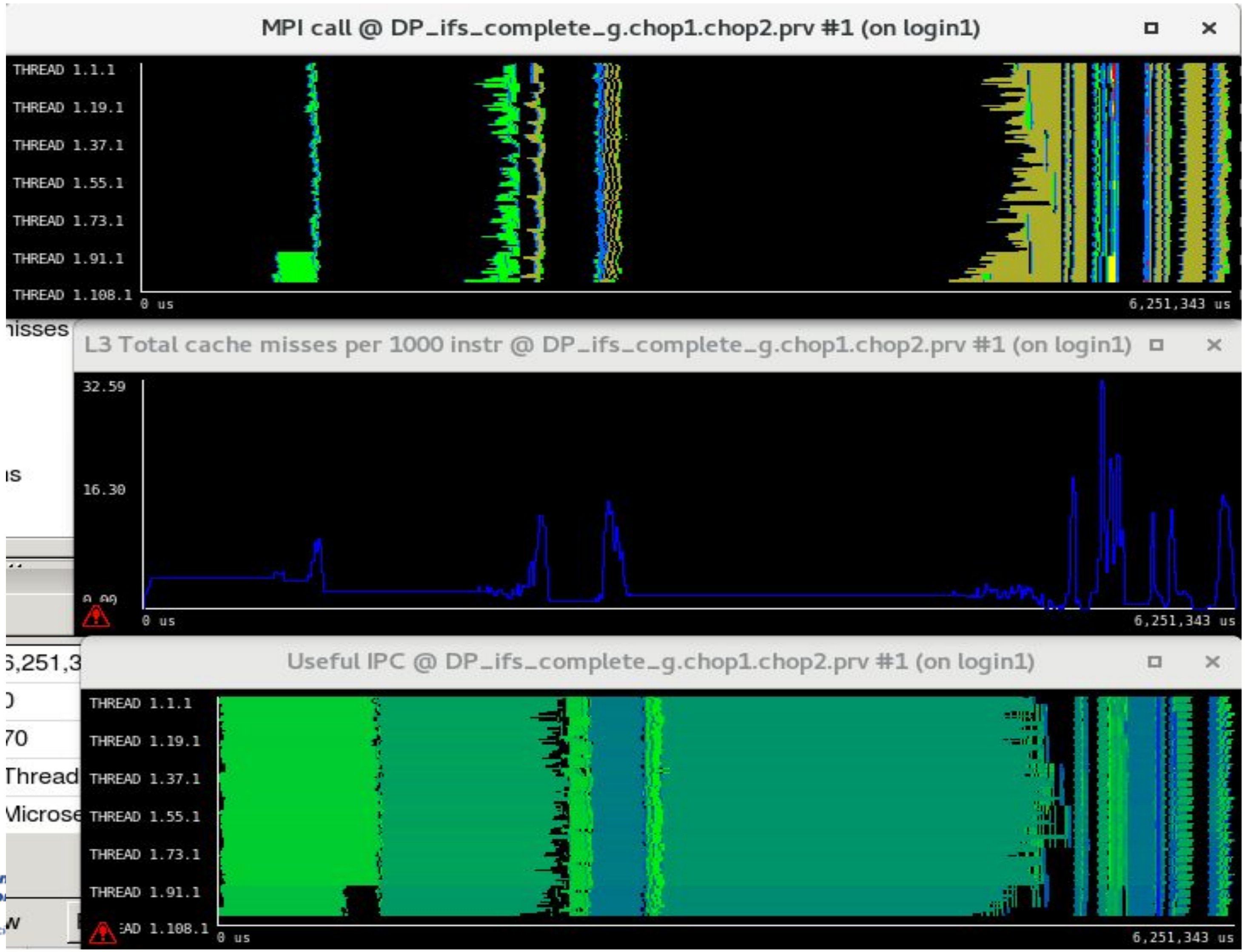
	108	108
Parallel efficiency	79.85%	80.55%
Load balance	93.66%	93.33%
Communication efficiency	85.25%	86.31%
Serialization efficiency	89.34%	89.89%
Transfer efficiency	95.43%	96.01%
Computation scalability	100.00%	154.10%
Global efficiency	79.85%	124.13%
IPC scalability	100.00%	133.11%
Instruction scalability	100.00%	115.50%
Frequency scalability	100.00%	100.23%
Speedup	1.00	1.55
Average IPC	1.22	1.62
Average frequency (GHz)	2.39	2.40

PAPI Counters

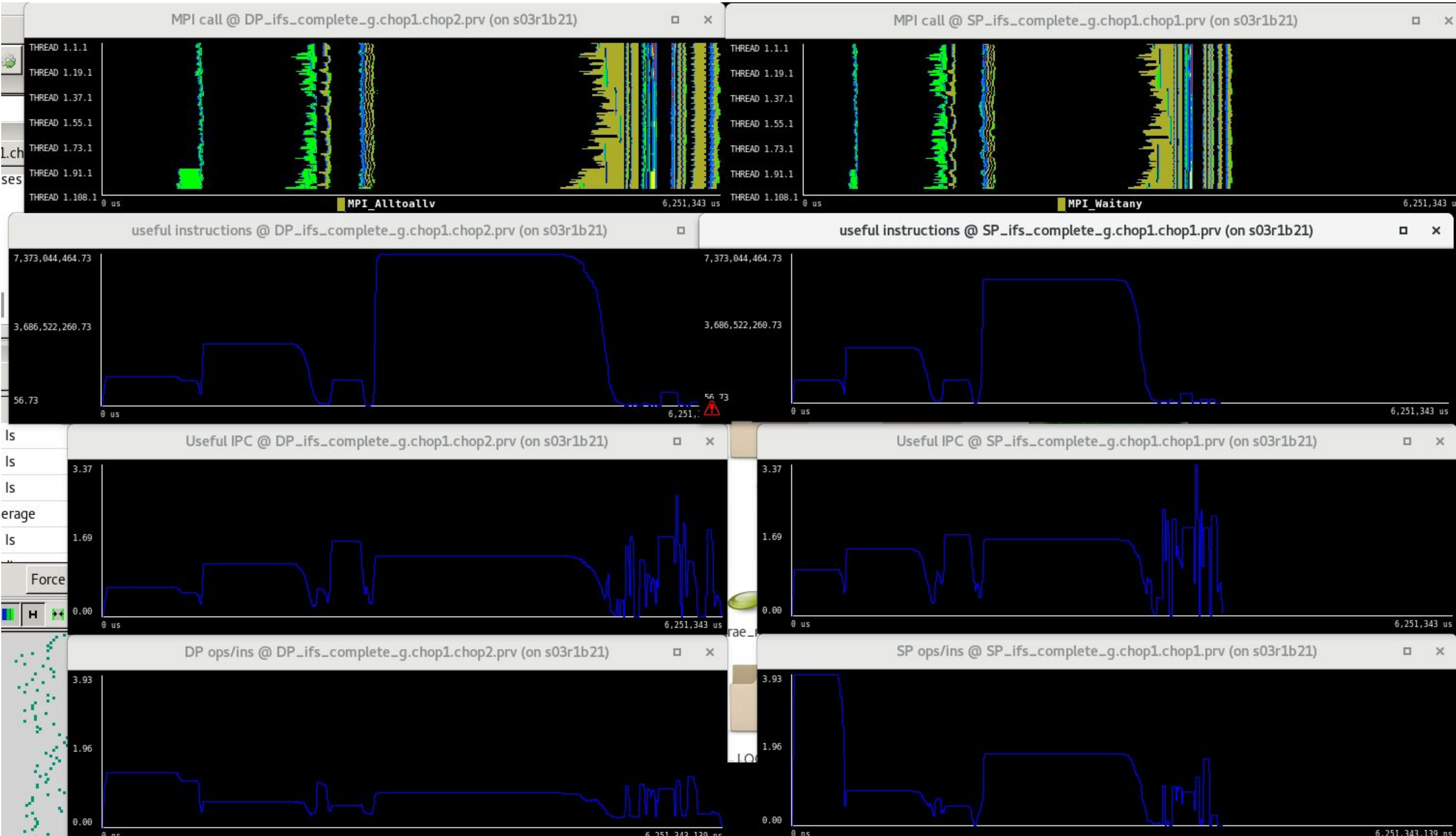
- PAPI counters collected during the execution
- Some of them are based on other native PAPI counters and derived from the base metrics

	Derived
Instructions	
Cycles	
Useful Duration	X
Useful Instructions	X
Useful IPC	X
Loads	
Stores	
L3/L2/L1_Total_Misses	
L3/L2/L1_MISS_RATIO	X
FP_OPS	
FP_TOT_INS	
INS_VEC	X

PAPI Counters

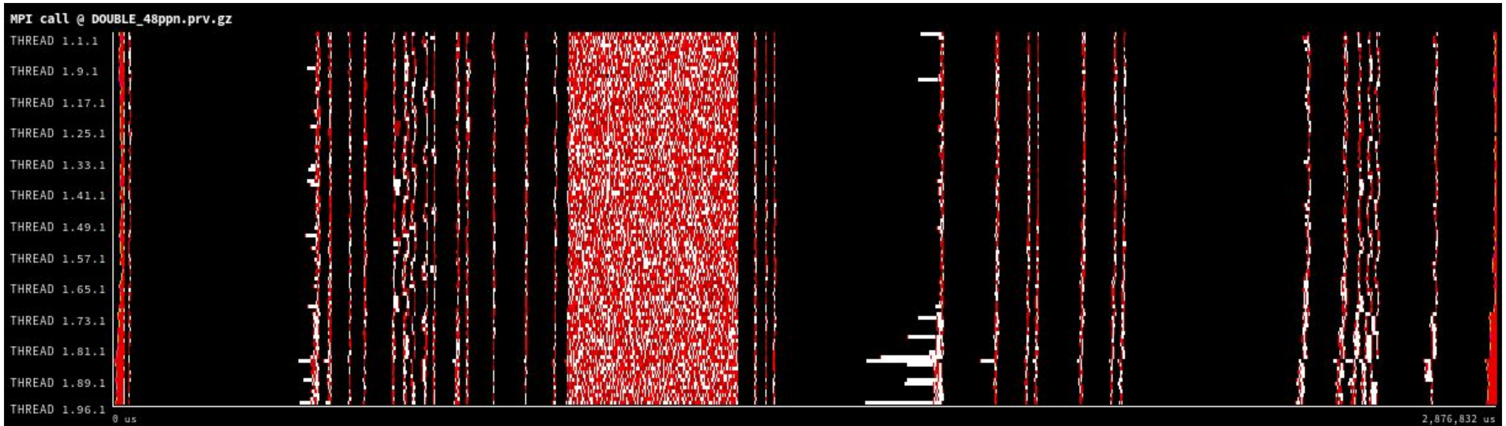


PAPI Counters

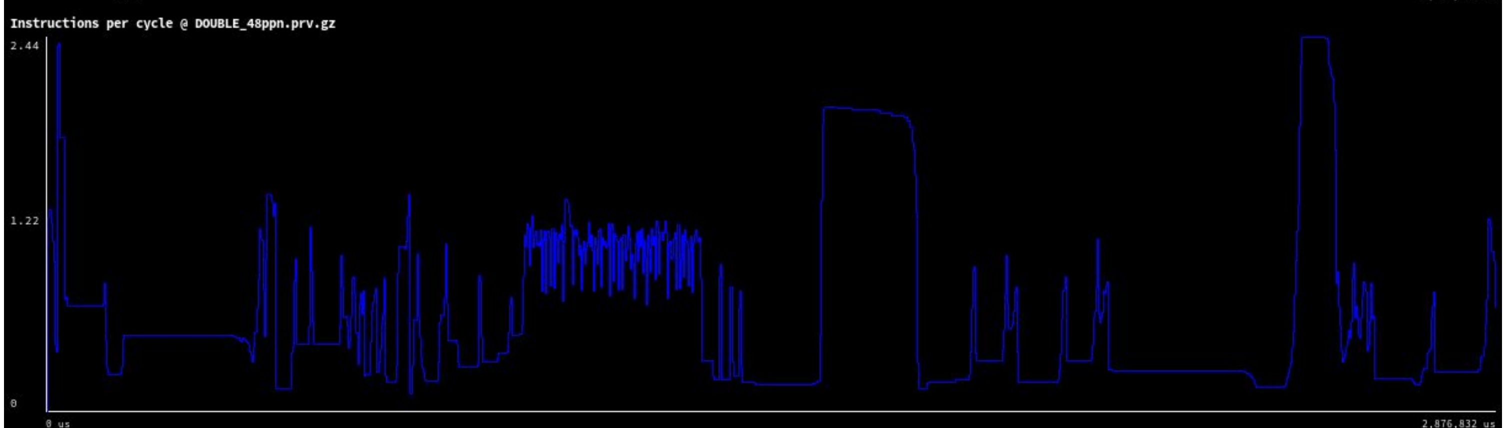


PAPI Counters

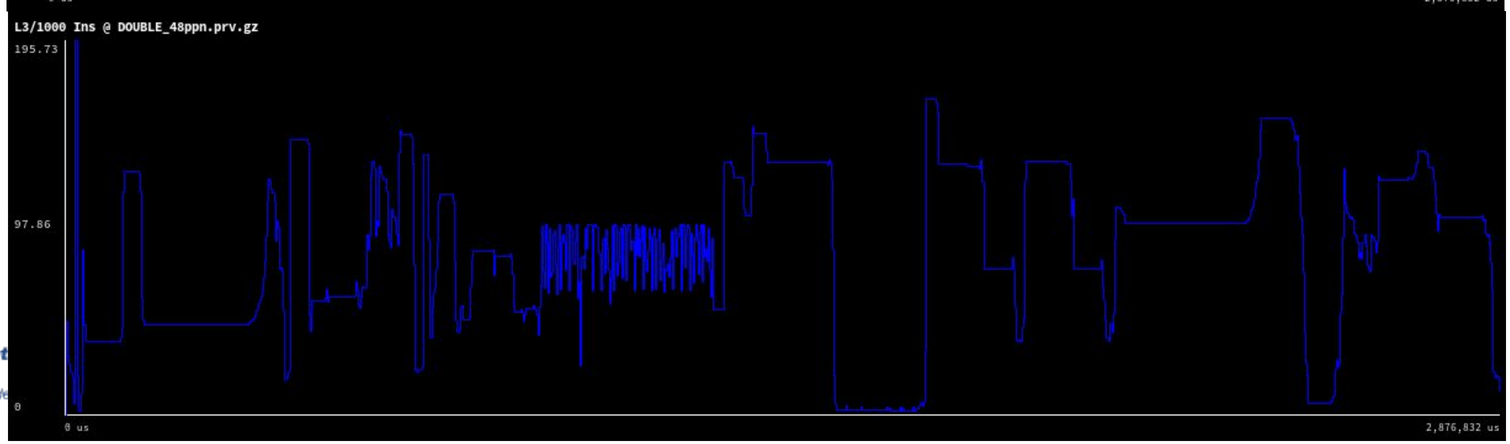
MPI Events



IPC



L1 Misses per 1000 INS



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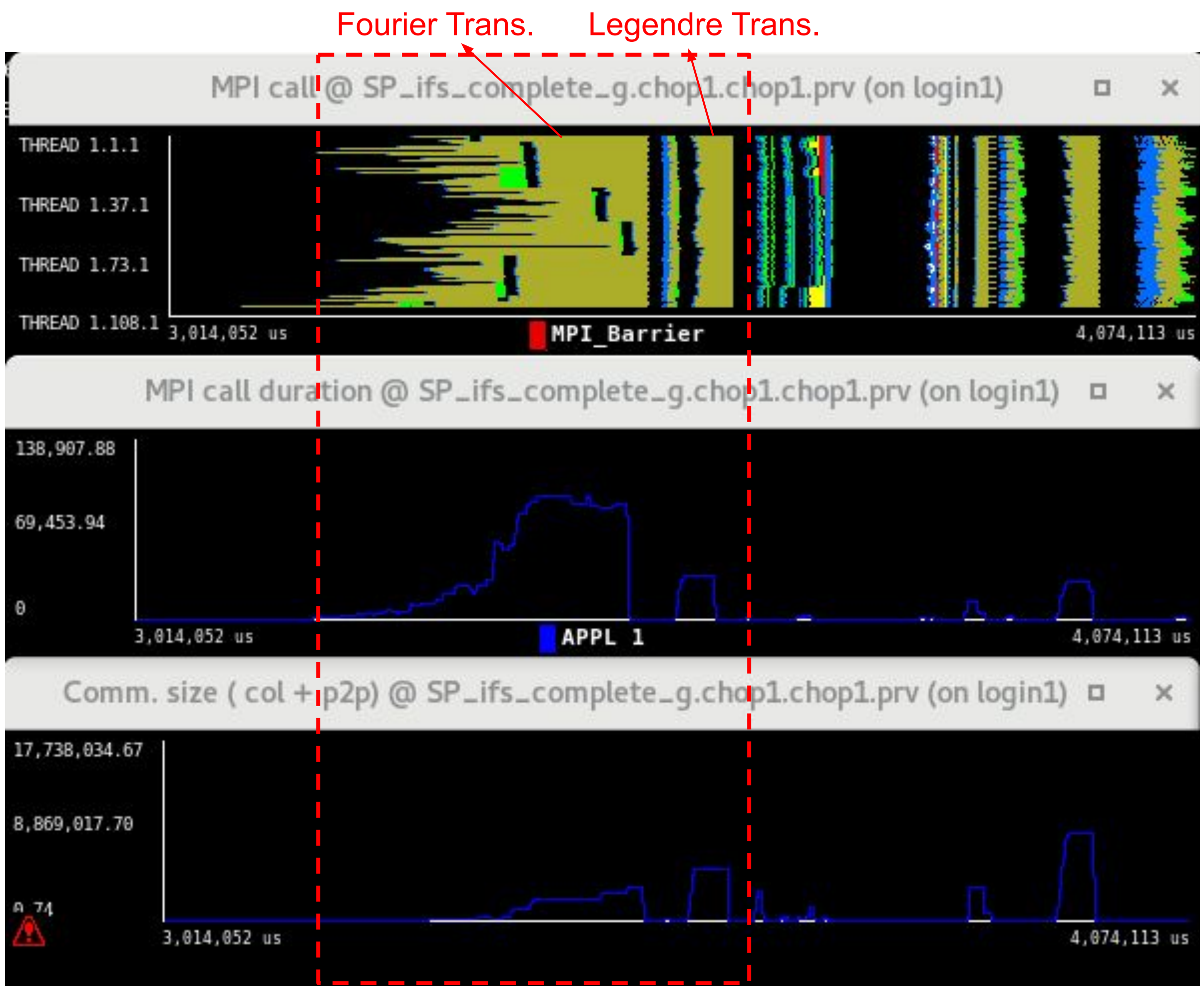
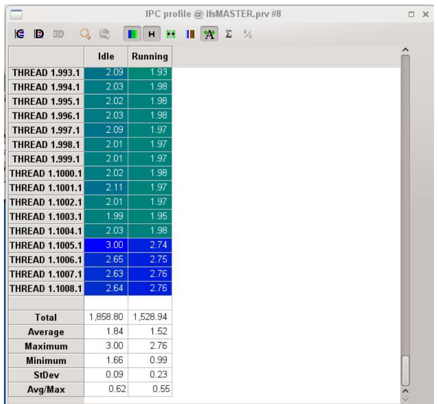
MPI evaluation



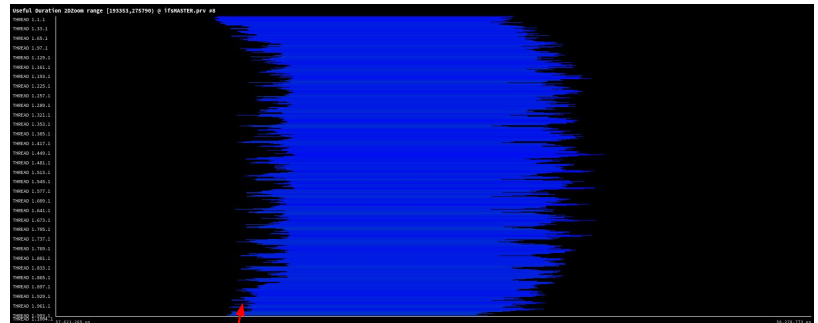
MPI evaluation

- IPC less than 1 for calculation areas?
- Are there load imbalance regions?


IPC profile @ ifsMASTER.prv #8

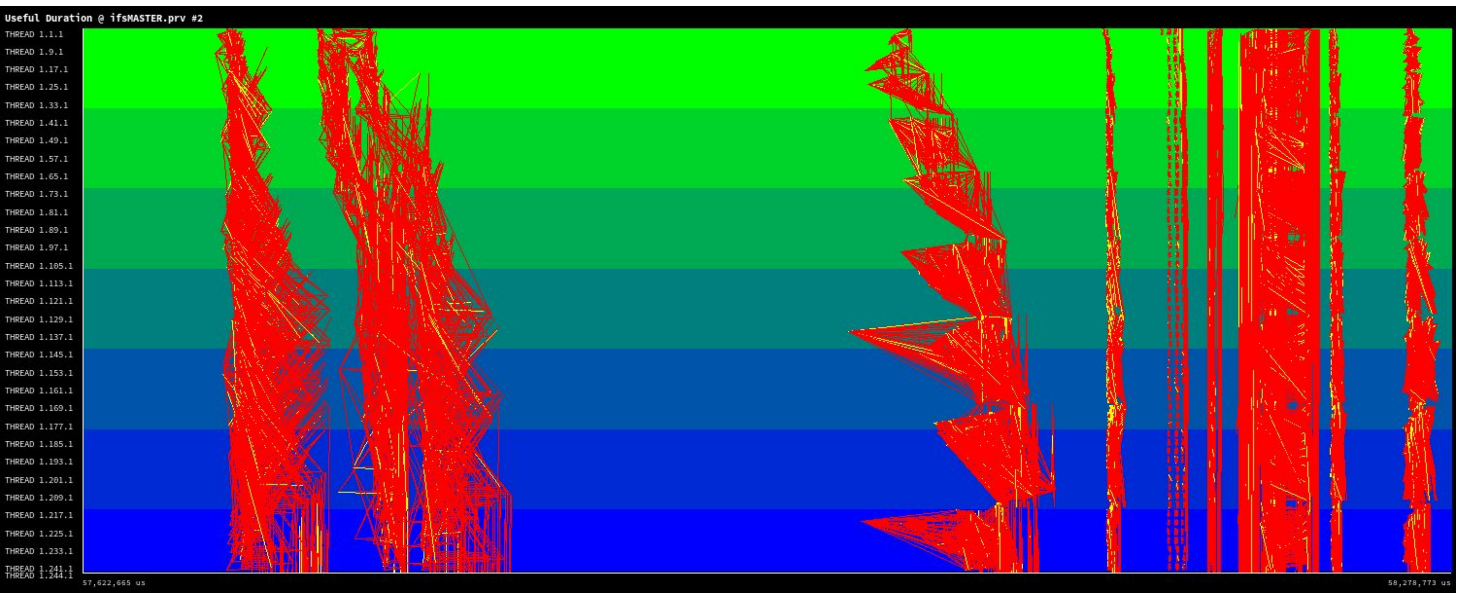
	Idle	Running
THREAD 1.993.1	2.09	1.93
THREAD 1.994.1	2.03	1.98
THREAD 1.995.1	2.02	1.98
THREAD 1.996.1	2.03	1.98
THREAD 1.997.1	2.09	1.97
THREAD 1.998.1	2.01	1.97
THREAD 1.999.1	2.01	1.97
THREAD 1.1000.1	2.02	1.98
THREAD 1.1001.1	2.11	1.97
THREAD 1.1002.1	2.01	1.97
THREAD 1.1003.1	1.99	1.95
THREAD 1.1004.1	2.03	1.98
THREAD 1.1005.1	3.00	2.74
THREAD 1.1006.1	2.65	2.75
THREAD 1.1007.1	2.63	2.76
THREAD 1.1008.1	2.64	2.76
Total	1,858.80	1,528.94
Average	1.84	1.52
Maximum	3.00	2.76
Minimum	1.66	0.99
StDev	0.09	0.23
Avg/Max	0.62	0.55

IPC_Profile



MPI evaluation

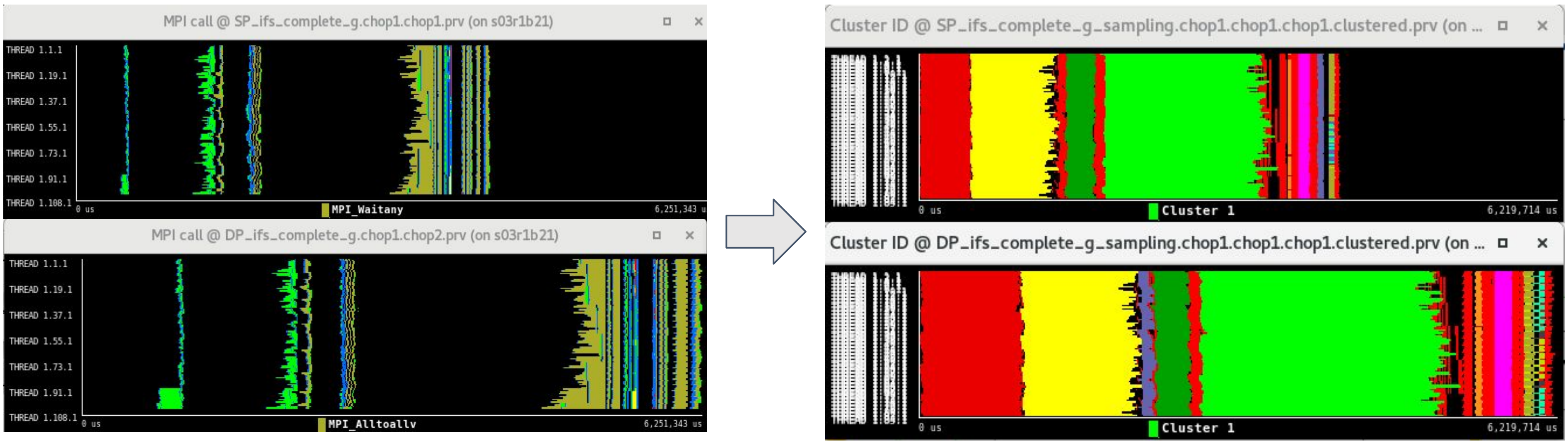
- Are MPI communications efficient according to the map affinity?



Affinity per node

Clustering Tool

Applying Clustering for an automatic profiling analysis

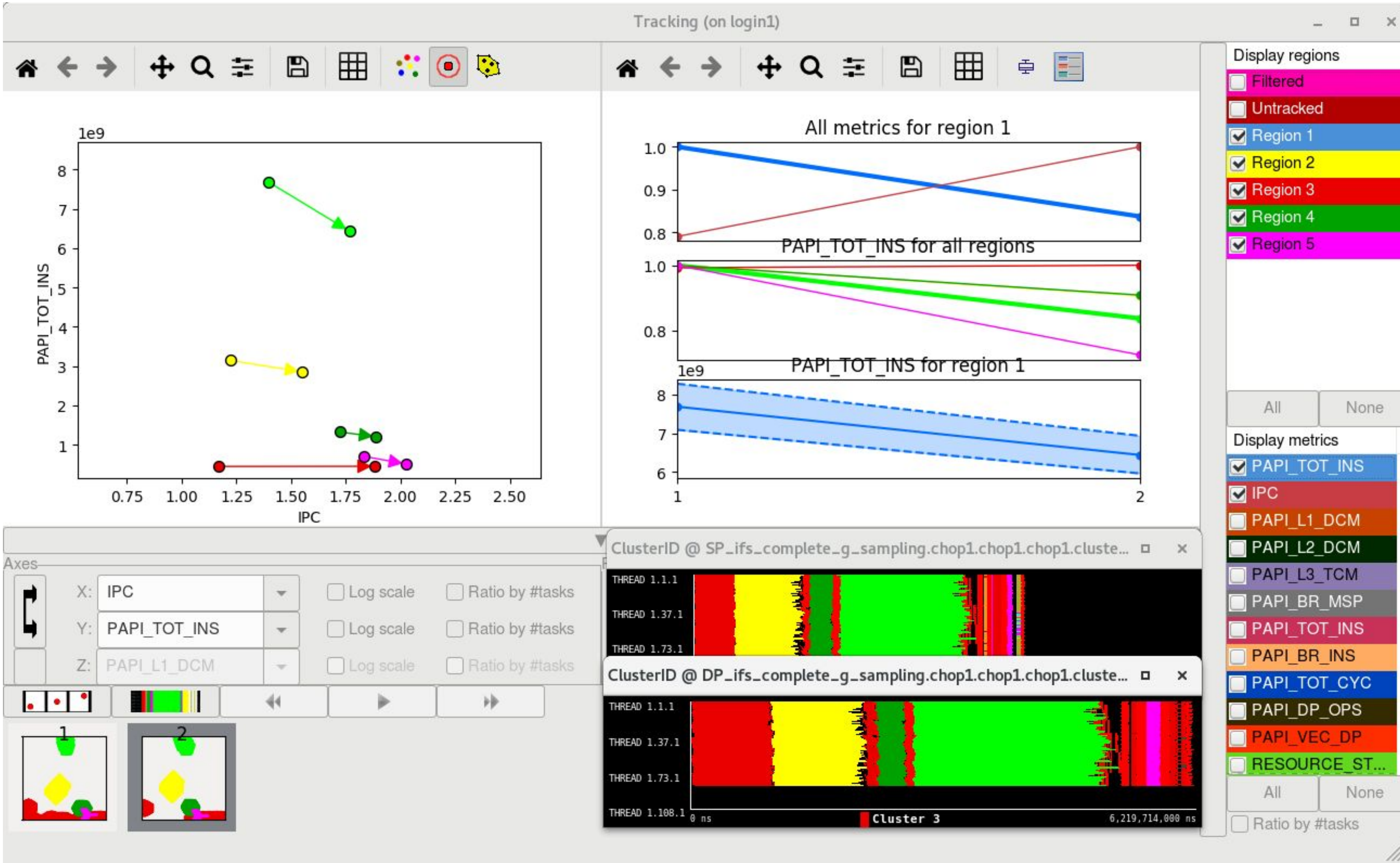


- Characterizes computing bursts that are similar and groups them into clusters
- Allows to study the behavior of the clusters separately, identify patterns, etc.

Tracking Tool

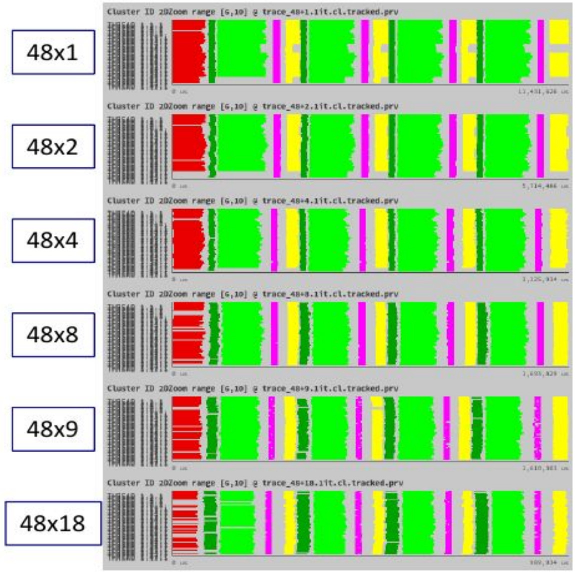
- A friendly way to quantify and visualize the evolution of the clusters among several traces
- The tool has 2 parts
  - Recognition algorithm of “who-is-who”, based on heuristics
  - A visualization GUI
- Examples analyzing multiple traces
  - Scaling number of MPI/OpenMP resources (64 – 128 – 256…)
  - Testing different microarchitecture features
  - Changing the problem size
  - Trying different compiler optimizations

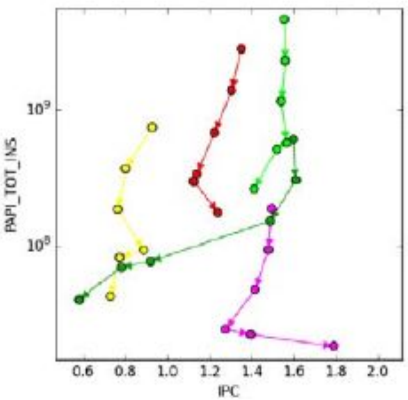
Tracking Tool

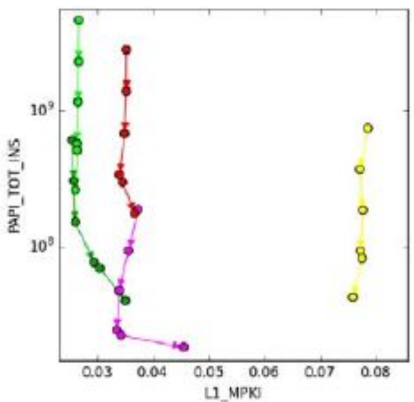


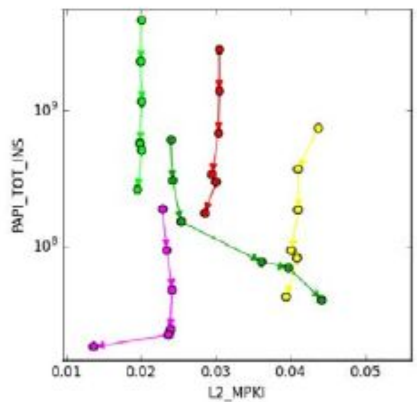
Tracking Tool

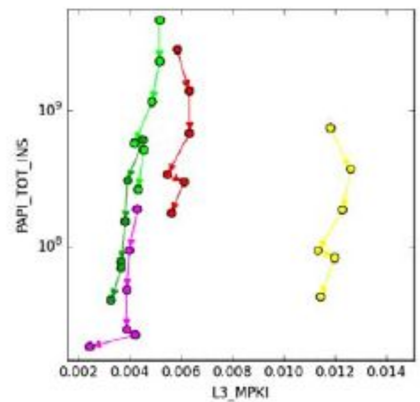
Tracking IFS MPI+OMP Strong Scaling

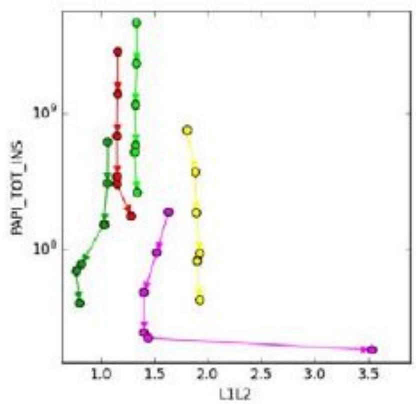


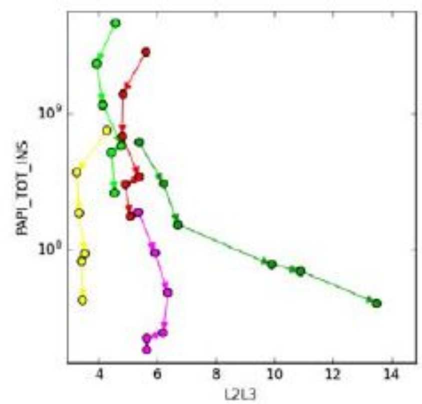








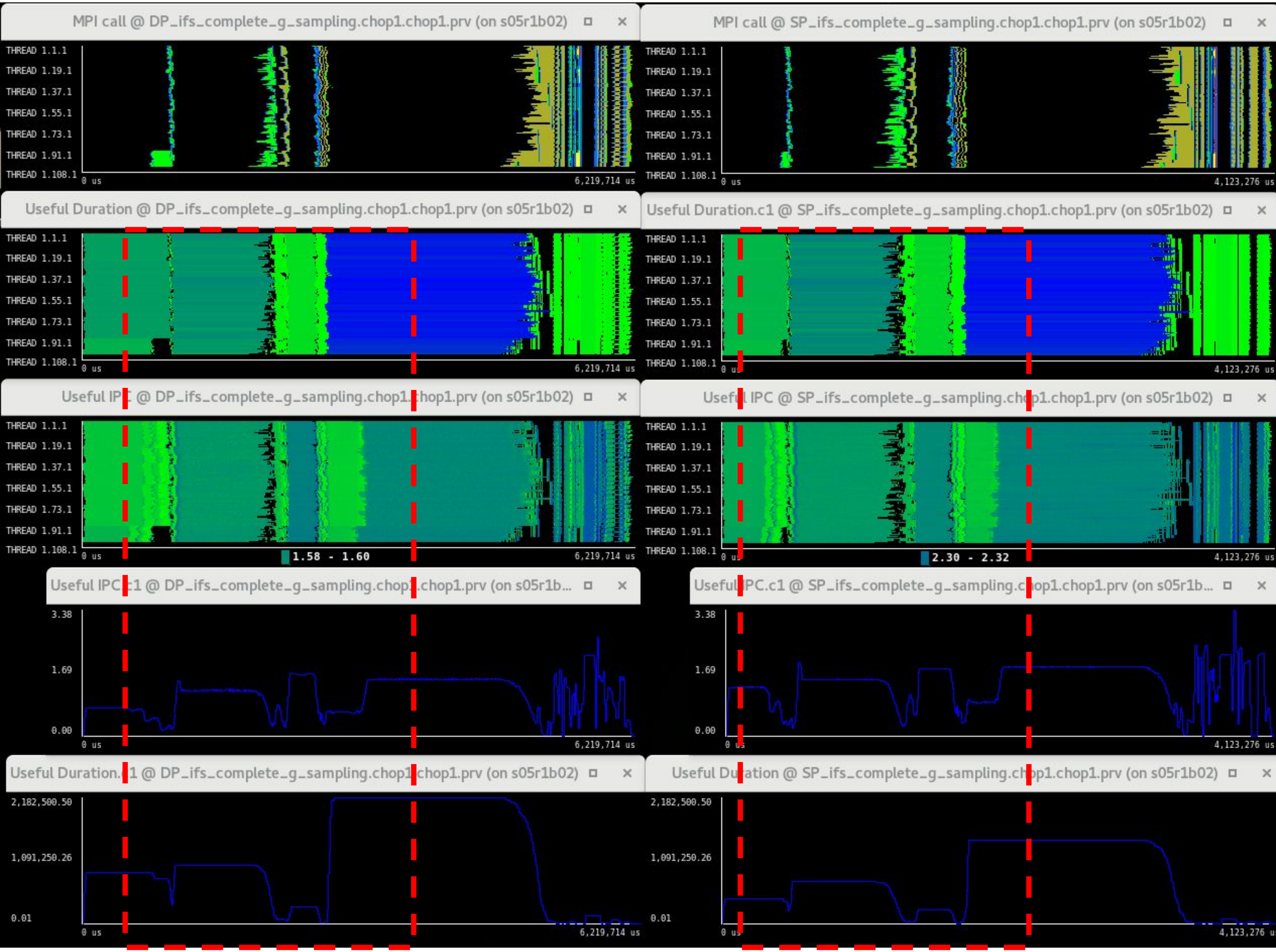




Sampling Tool

- Extrae can be configured to capture performance metrics on a periodic basis using alarm signals and specifying period and variability (10 and 2 respectively for IFS and NEMO tests).
- This means that we will capture samples every 10 ms with a random variability of 2 ms.

- Every sample contains processor performance counters (where every PAPI counter is referred at configured time) and callstack information.

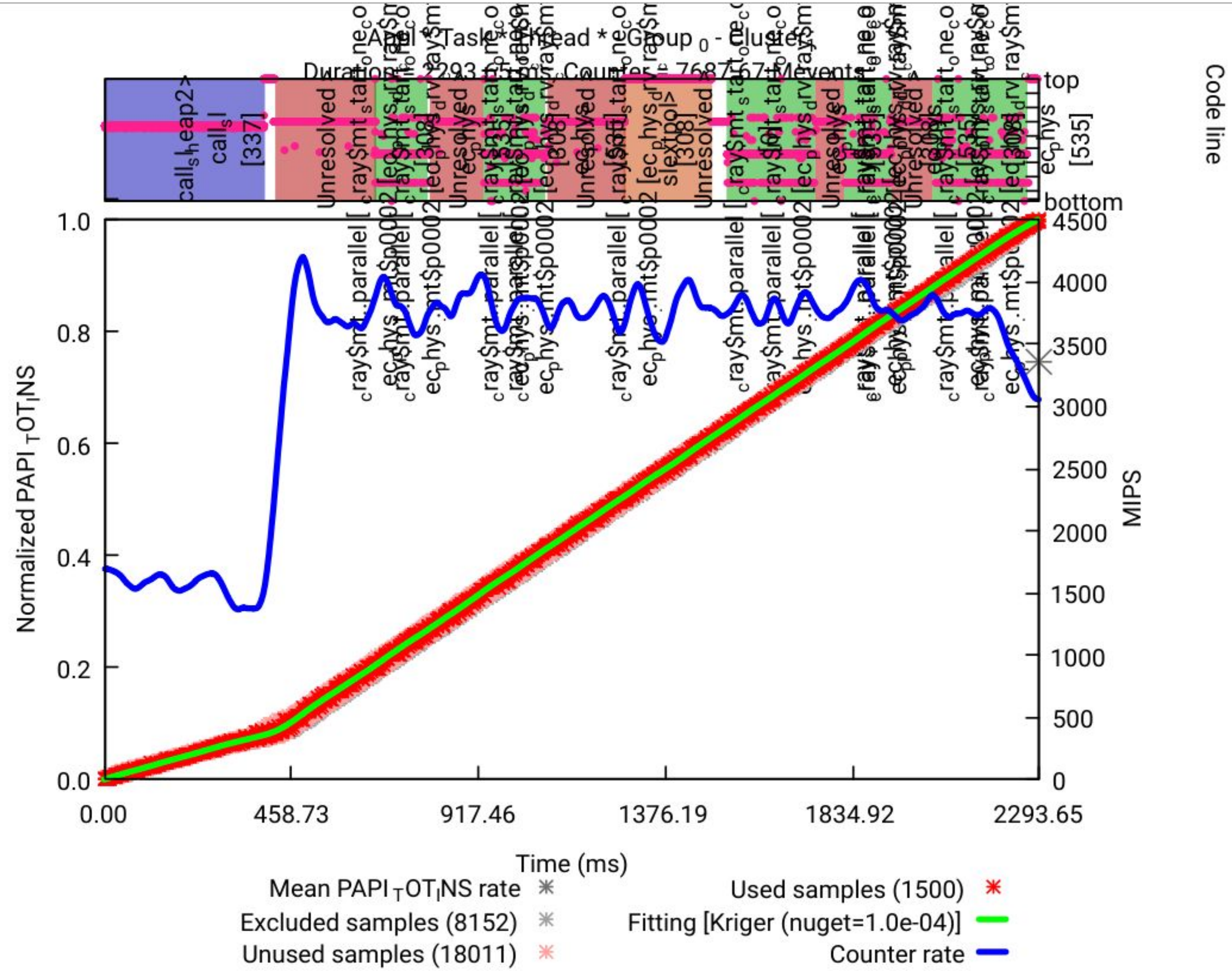


MPI call @ DP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
MPI call @ SP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
THREAD 1.1.1
THREAD 1.19.1
THREAD 1.37.1
THREAD 1.55.1
THREAD 1.73.1
THREAD 1.91.1
THREAD 1.108.1
0 us
6,219,714 us
4,123,276 us
Useful Duration @ DP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
Useful Duration.c1 @ SP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
Useful IPC @ DP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
Useful IPC @ SP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
1.58 - 1.60
2.30 - 2.32
Useful IPC.c1 @ DP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b...
Useful IPC.c1 @ SP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b...
3.38
1.69
0.00
Useful Duration.c1 @ DP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
Useful Duration @ SP_ifs_complete_g_sampling.chop1.chop1.prv (on s05r1b02)
2,182,500.50
1,091,250.26
0.01

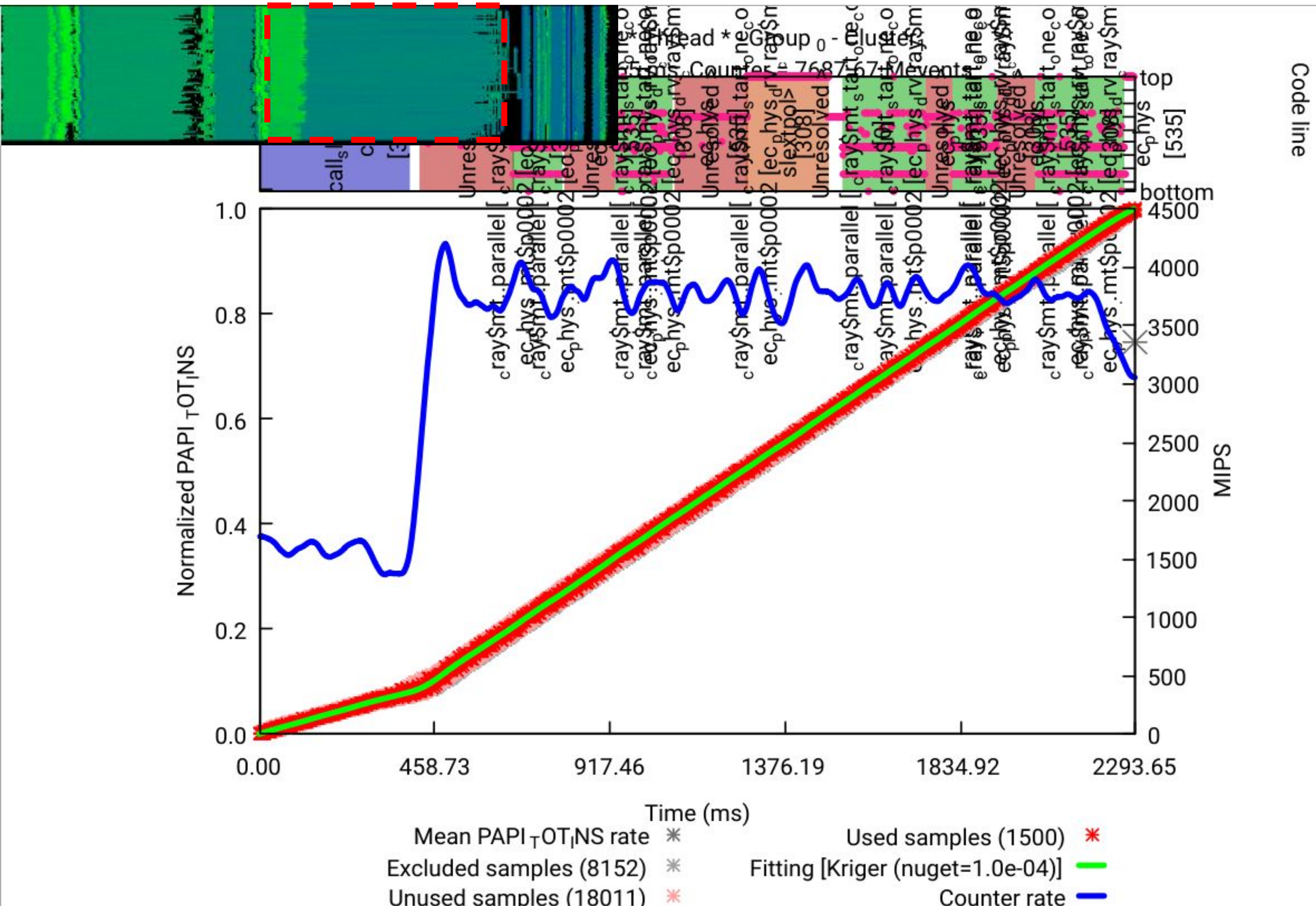
Folding Tool

- Combine instrumentation and sampling to provide **instantaneous performance metrics**, source code and memory references. This mechanism receives a trace-file and generates plots showing the fine evolution of the performance.
- The samples collected are gathered from scattered computing regions into a synthetic region by preserving their relative time within their original region so that the sampled information determines how the performance evolves within the region.
- The performance evolution is connected to source code and memory references at the same time.

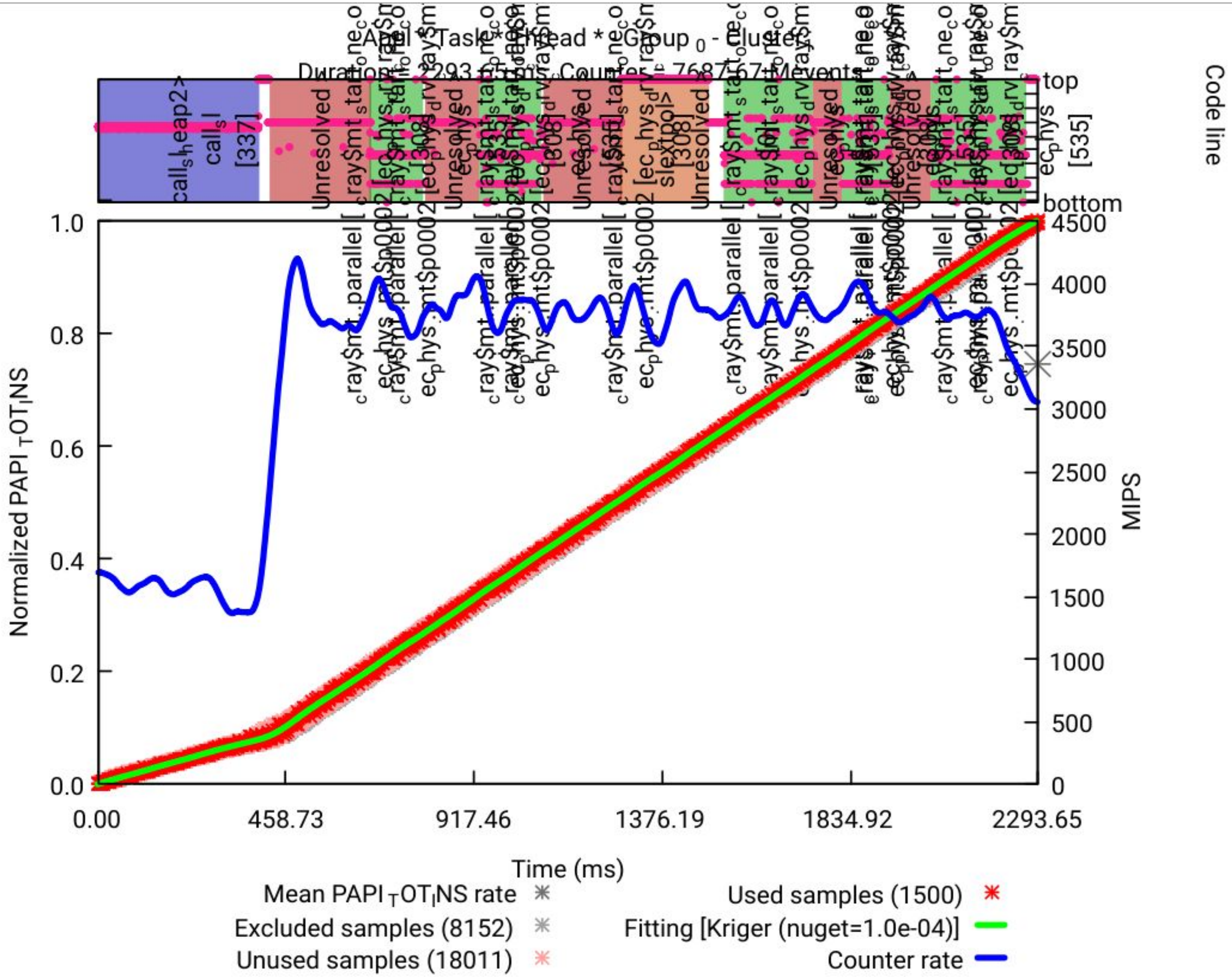
Folding Tool



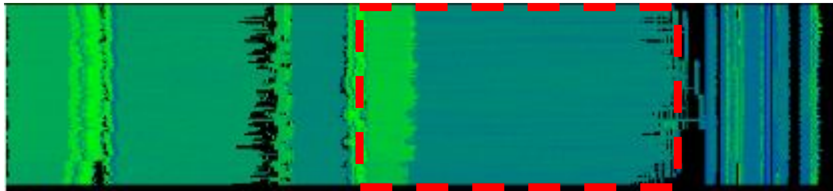
Folding Tool



Folding Tool



Folding Tool

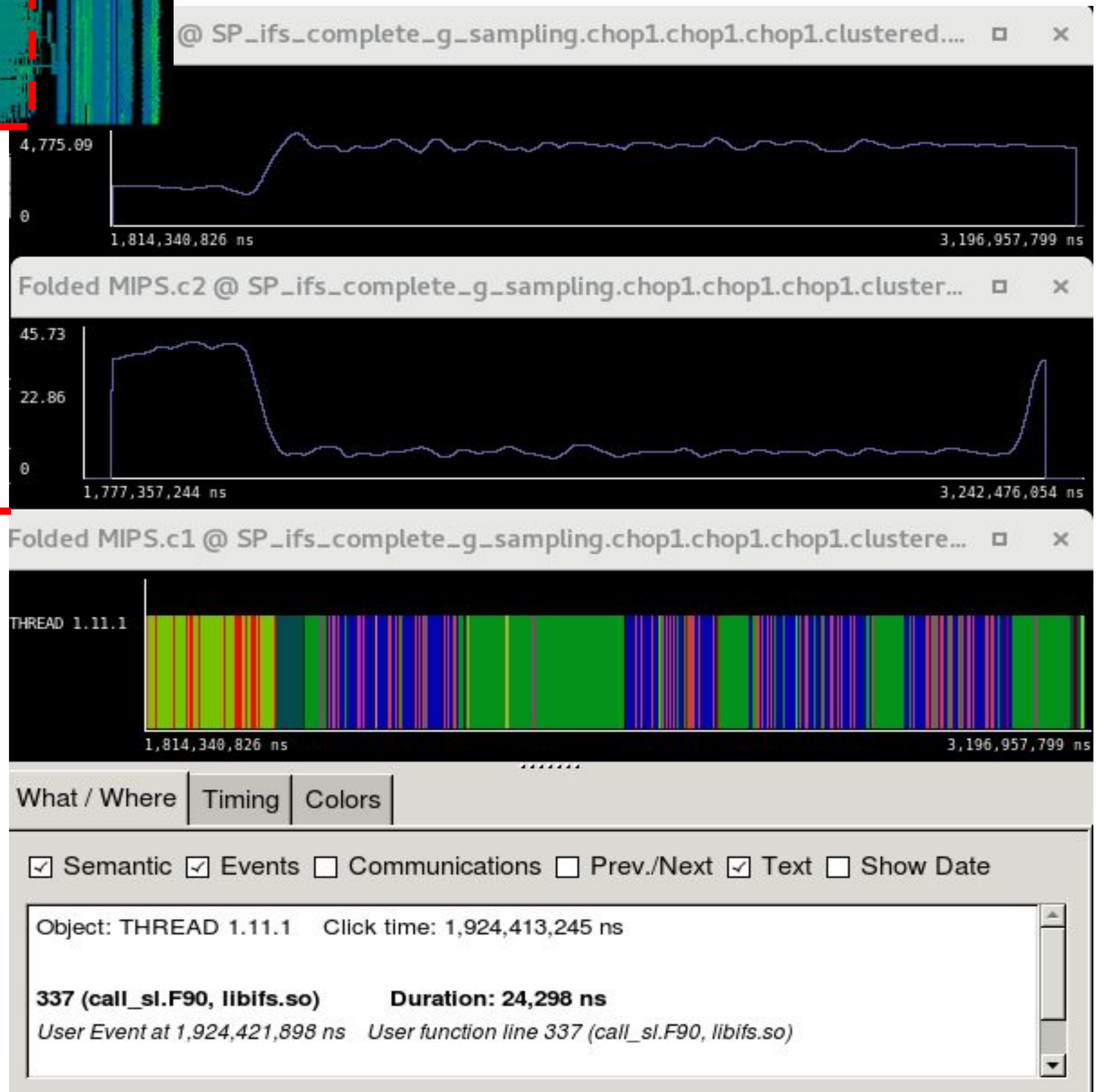


TOT_INS

TOT_CACHE_MISSES

Connection to the code

USER_FUNCTION_LINE



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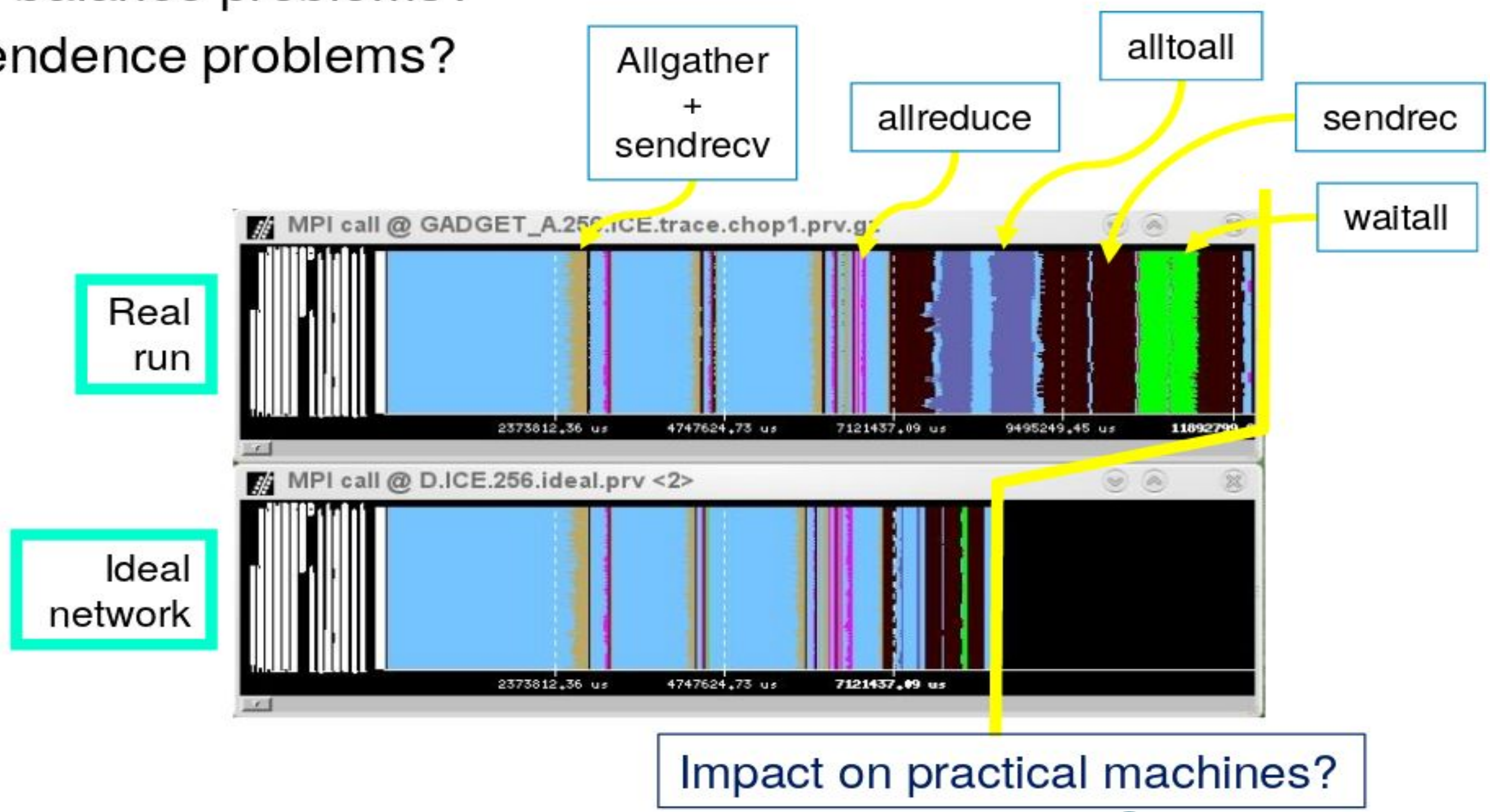
DIMEMAS Tool

The impossible machine: BW = ∞, L = 0

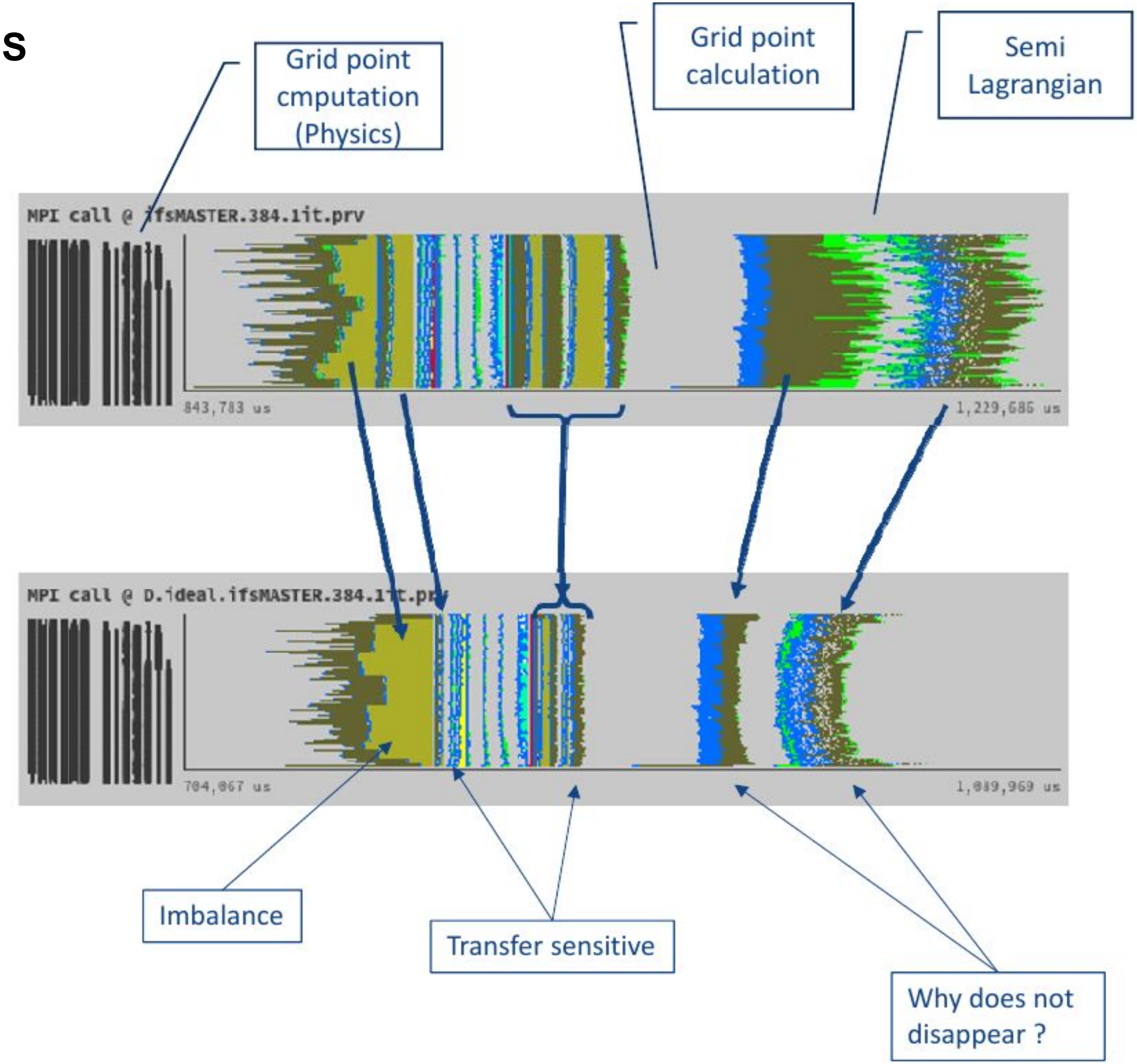
- Actually describes/characterizes intrinsic application behavior
  - Load balance problems?
  - Dependence problems?



DIMEMAS Tool

Ideal Network for IFS execution

- Actual run
- Ideal network



Profiling Methodology

- Area of study
- Deployment efficiency
- Benchmarking
- Profiling analysis
- **Validation**
  - Reproducibility Test
  - Validation Test

Validation

Reproducibility Test: Are your results comparable to the EC-Earth community results?

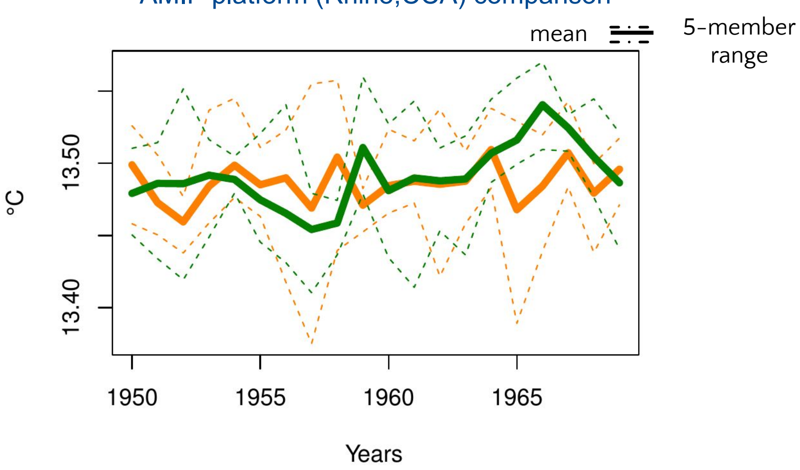
The Test proposed:

20-yr long, 5-member, Forcing Fixed Cmip and Amip simulations

- **20-yr long**: Allows to look at impact of machine on mean state/bias (not possible in the case of 1-yr simulations)
- **5-member**: Allows to measure differences due hardware as compared to internal variability
- **Forcing Fixed**: Working under stationary conditions removes possible dependence of hardware impact on the mean state
- **Cmip and Amip simulations**: Addresses the problem from a global point-of-view; suitable to give recommendations for CMIP6

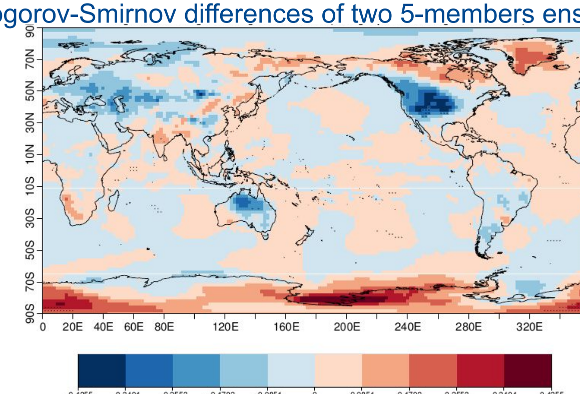
The results comparing platforms or configurations:

AMIP platform (Rhino;CCA) comparison



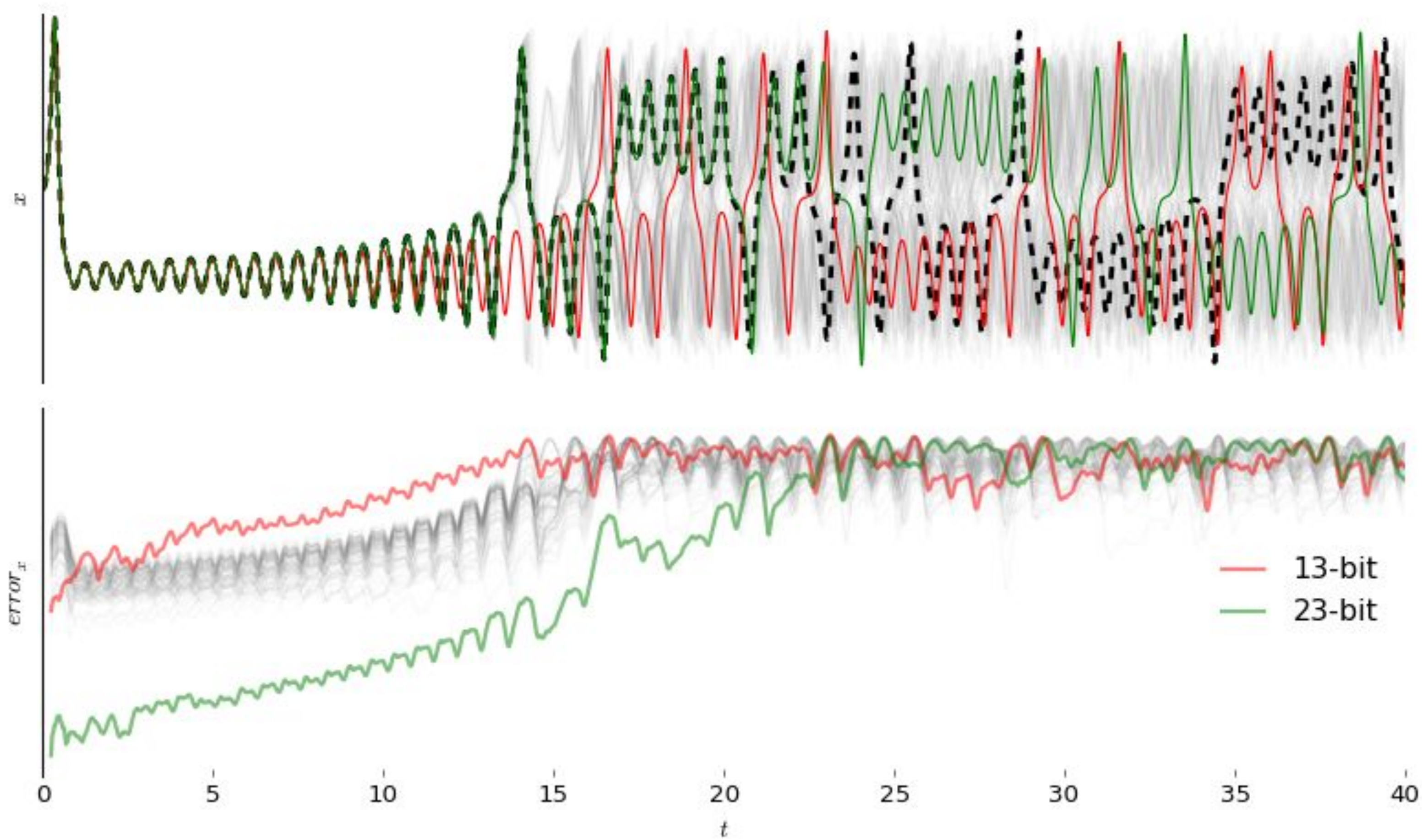
AMIP platform (Rhino;CCA) comparison

Kolmogorov-Smirnov differences of two 5-members ensambles



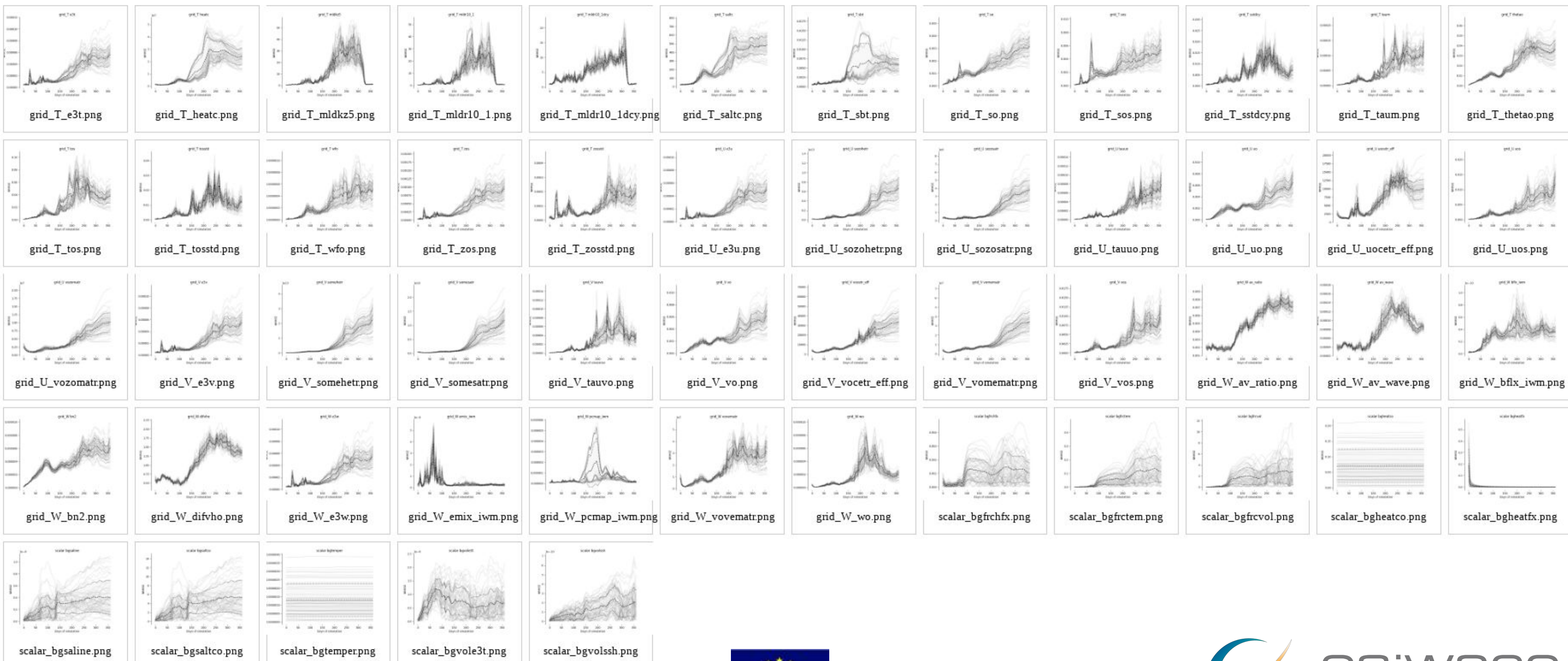
Validation Test

Verifying a non-linear model: a simple example



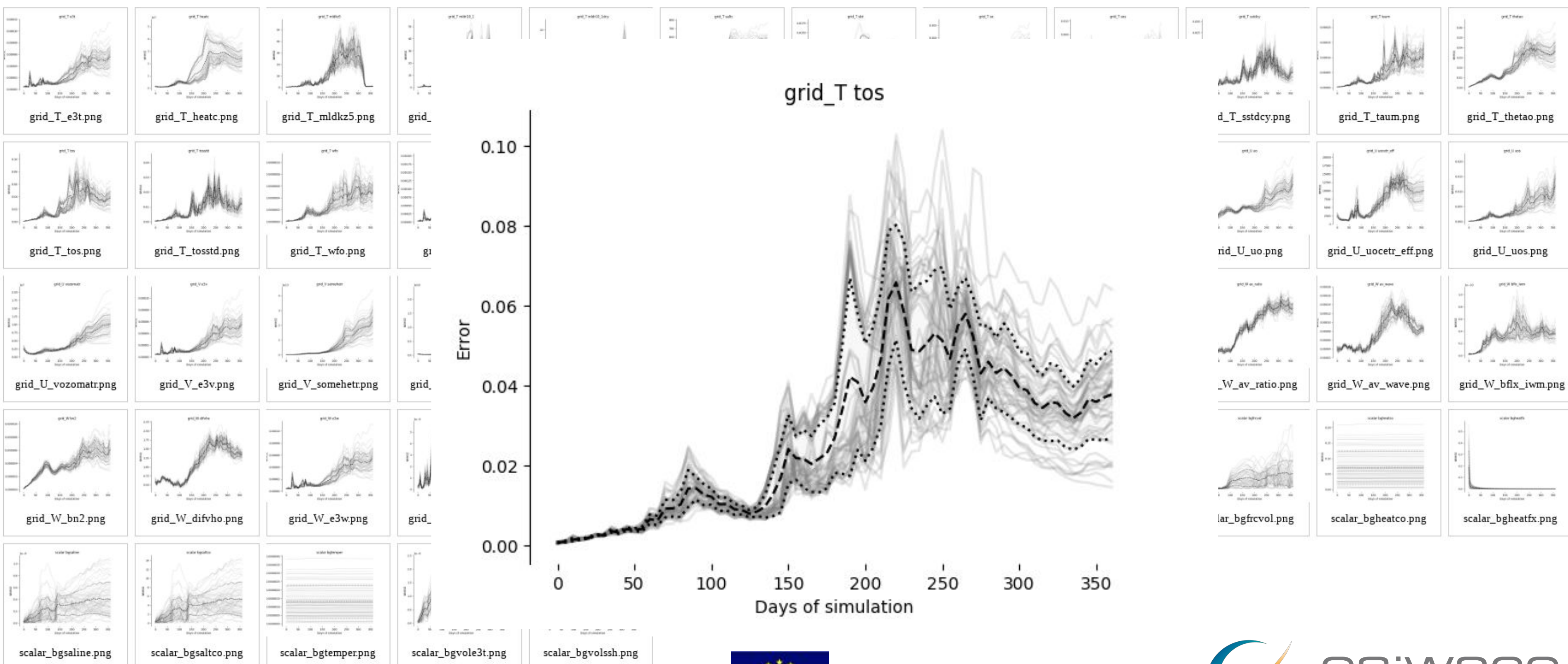
Validation Test (NEMO)

- Initial conditions perturbed with white noise in the 3D temperature field.
- Evaluating 53 output variables.



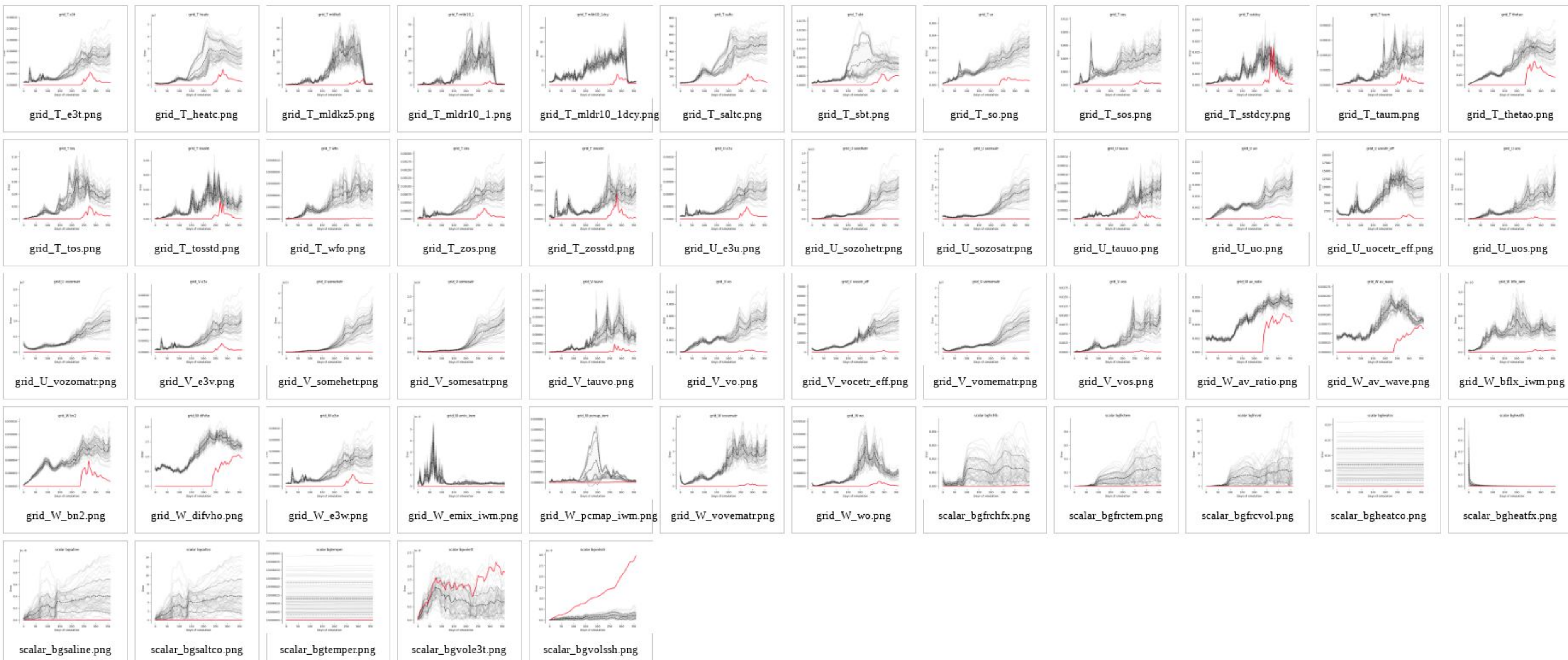
Validation Test (NEMO)

- Initial conditions perturbed with white noise in the 3D temperature field.
- Evaluating 53 output variables.



Validation Test (NEMO)

Example: Compiling with -xHost



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esiwace
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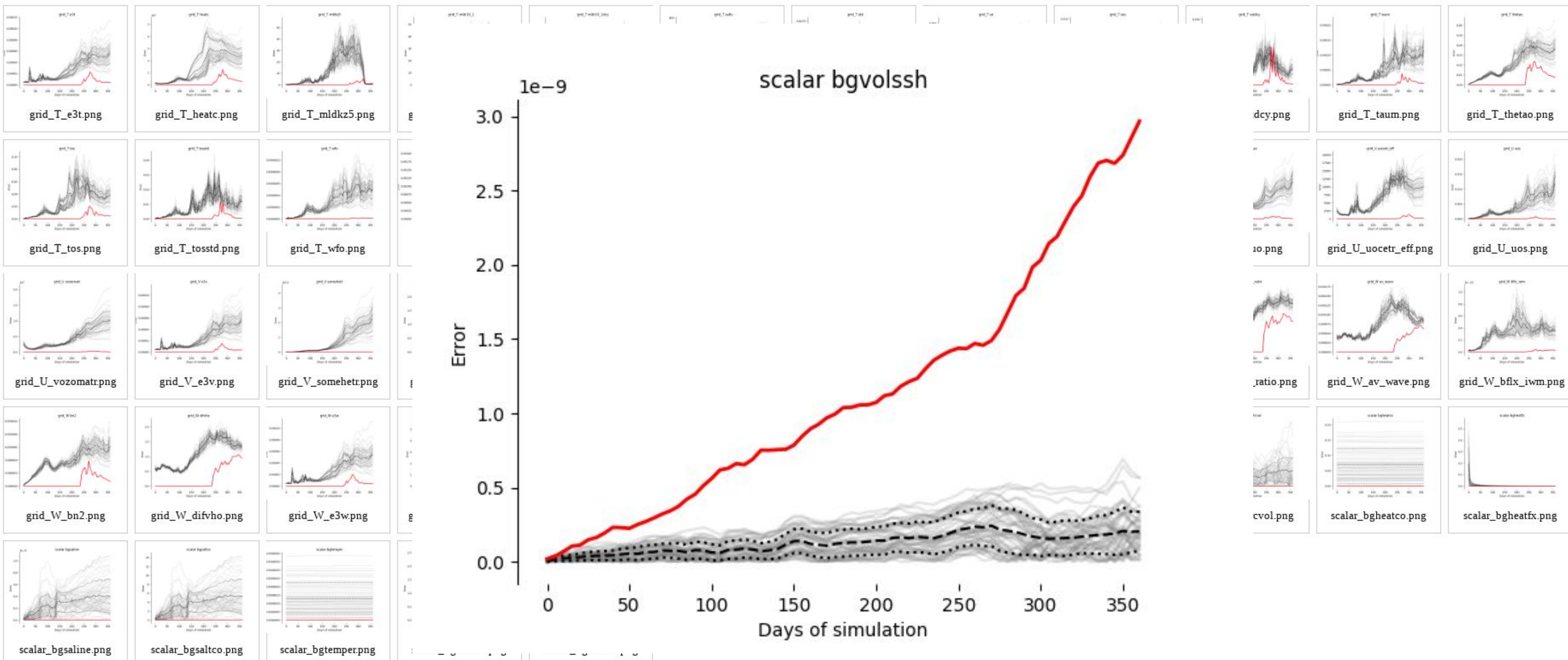
Validation Test (NEMO)

Example: Compiling with -xHost



Summary

- The complexity of our climate and weather models requires complexity for the methodologies used to study the computational performance.
- The methodology proposed can be used to find main bottlenecks across platforms, compiler options... for different configurations of the model.
- It can be used to compare computational optimizations (see now Single and Double precision comparison for IFS and NEMO!) and validate the results.
- Profiling analysis include different tools for different purposes:
  - EXTRAE+PARAVER
  - CLUSTERING+TRACKING
  - SAMPLING+FOLDING
  - DIMEMAS

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EXCELENCIA SEVERO OCHOA

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Thank you

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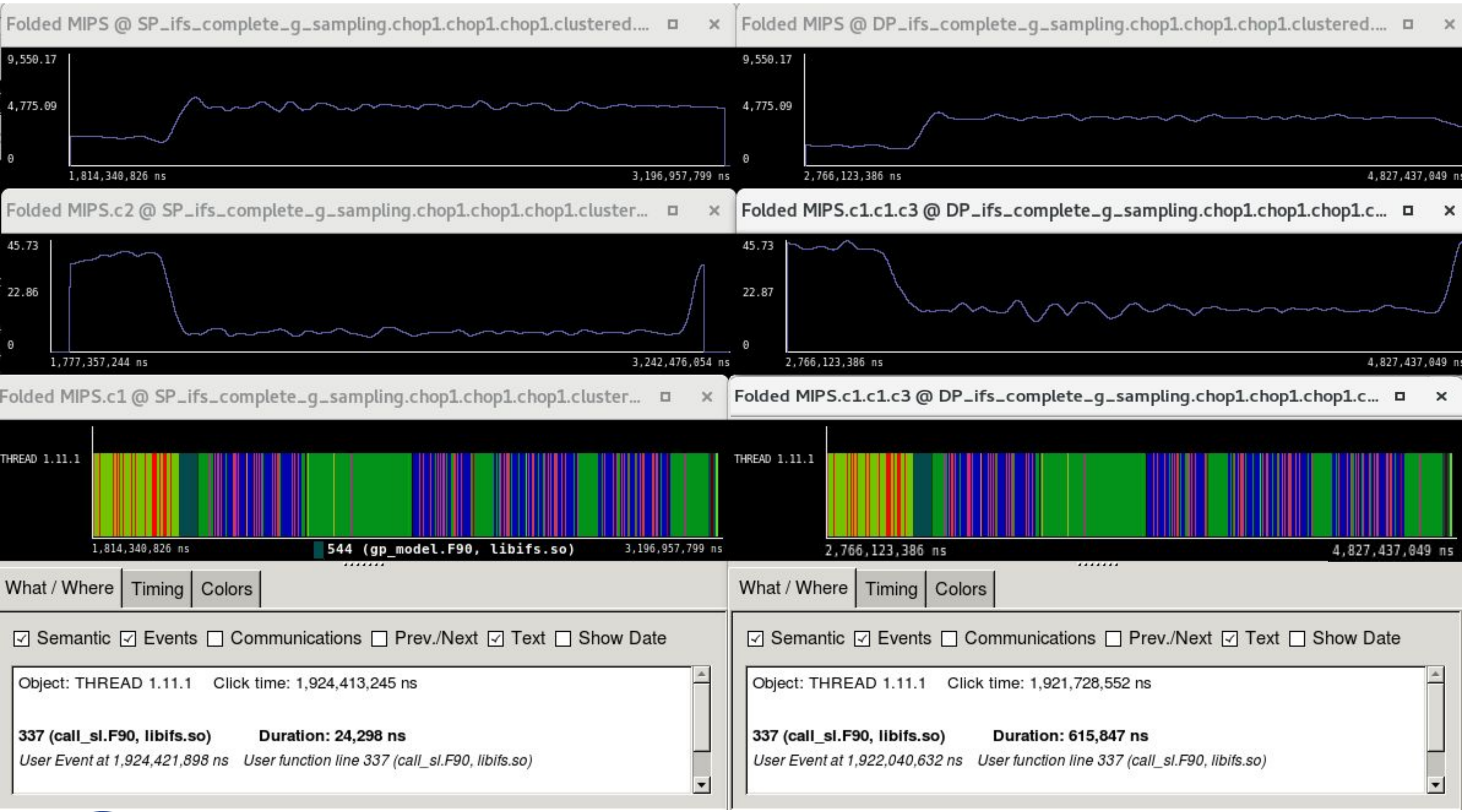
mario.acosta@bsc.es


Folded MIPS @ SP_ifs_complete_g_sampling.chop1.chop1.chop1.clustered....
9,550.17
4,775.09
0
1,814,340,826 ns
3,196,957,799 ns
Folded MIPS @ DP_ifs_complete_g_sampling.chop1.chop1.chop1.clustered....
9,550.17
4,775.09
0
2,766,123,386 ns
4,827,437,049 ns
Folded MIPS.c2 @ SP_ifs_complete_g_sampling.chop1.chop1.chop1.cluster...
45.73
22.86
0
1,777,357,244 ns
3,242,476,054 ns
Folded MIPS.c1.c1.c3 @ DP_ifs_complete_g_sampling.chop1.chop1.chop1.c...
45.73
22.87
0
2,766,123,386 ns
4,827,437,049 ns
Folded MIPS.c1 @ SP_ifs_complete_g_sampling.chop1.chop1.chop1.cluster...
THREAD 1.11.1
1,814,340,826 ns
544 (gp_model.F90, libifs.so)
3,196,957,799 ns
Folded MIPS.c1.c1.c3 @ DP_ifs_complete_g_sampling.chop1.chop1.chop1.c...
THREAD 1.11.1
2,766,123,386 ns
4,827,437,049 ns
What / Where
Timing
Colors
Semantic
Events
Communications
Prev./Next
Text
Show Date
Object: THREAD 1.11.1 Click time: 1,924,413,245 ns
337 (call_sl.F90, libifs.so) Duration: 24,298 ns
User Event at 1,924,421,898 ns User function line 337 (call_sl.F90, libifs.so)
What / Where
Timing
Colors
Semantic
Events
Communications
Prev./Next
Text
Show Date
Object: THREAD 1.11.1 Click time: 1,921,728,552 ns
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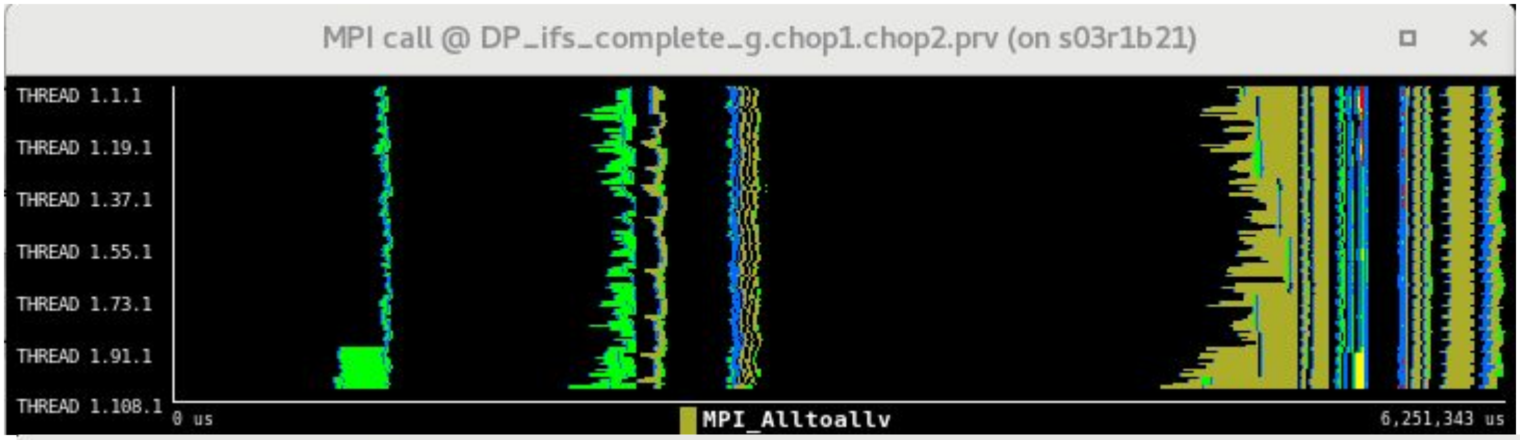
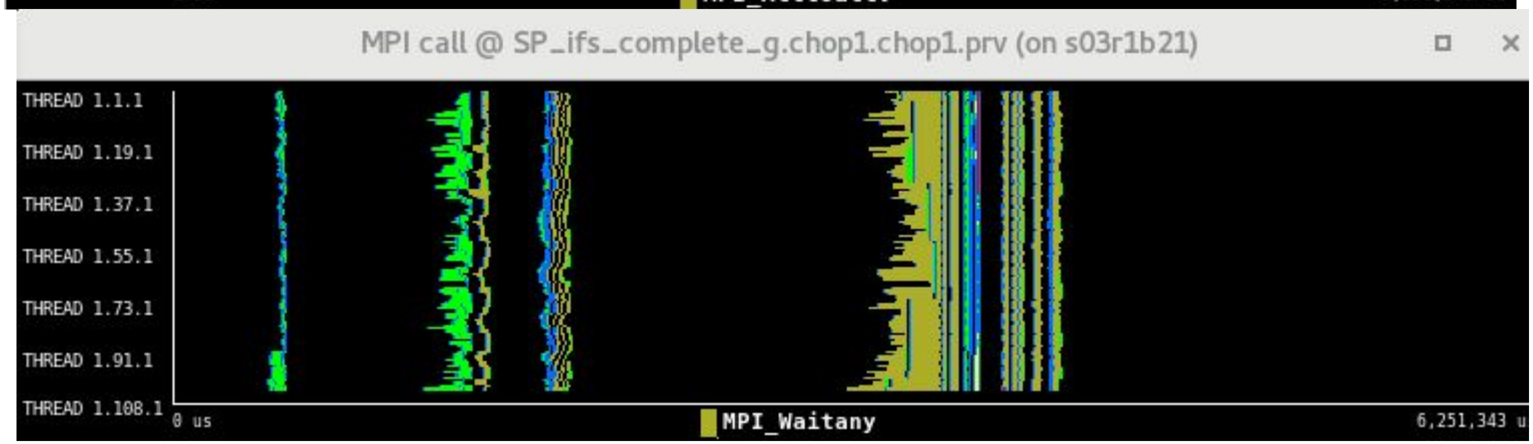
User Event at 1,922,040,632 ns User function line 337 (call_sl.F90, libifs.so)





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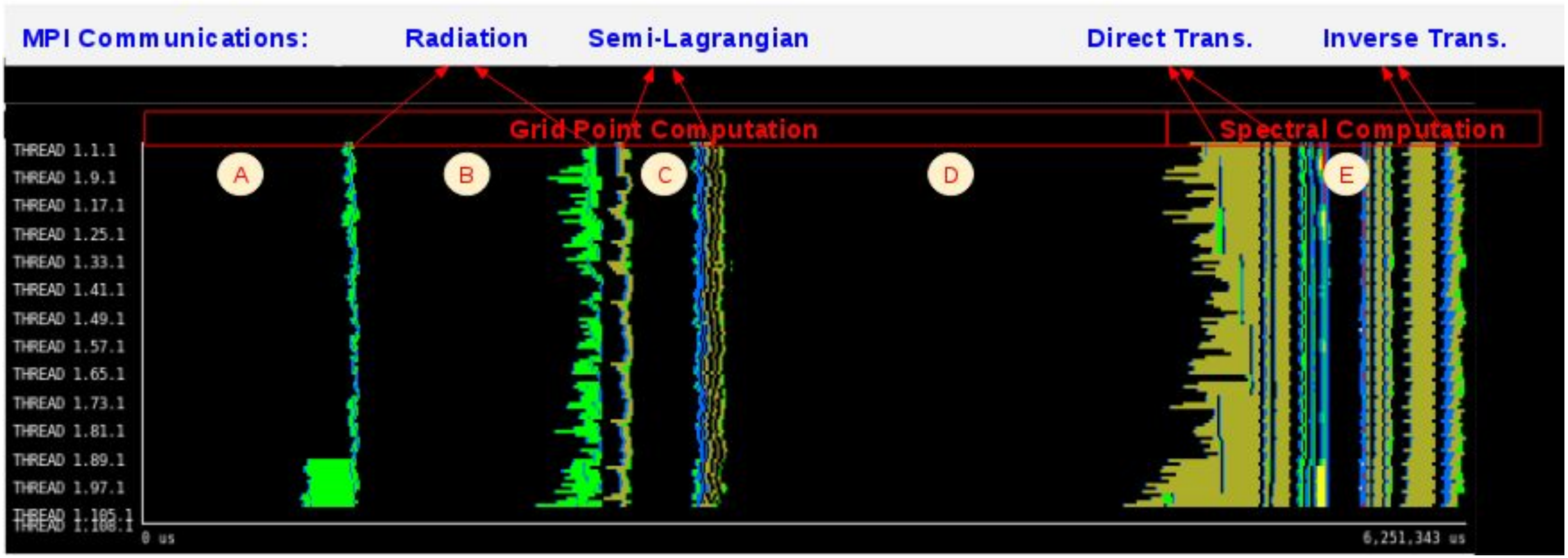
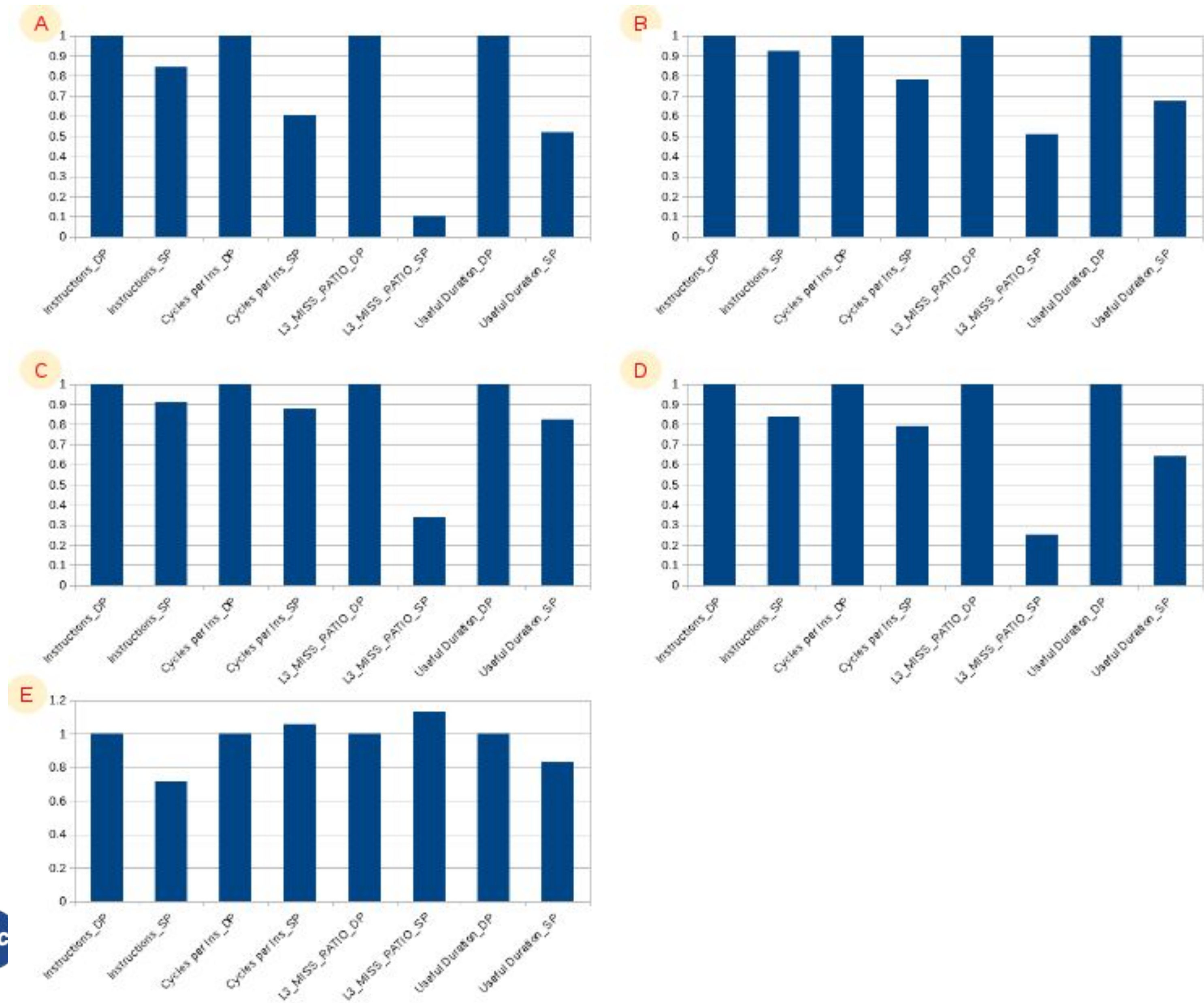

MPI Communications:
Radiation
Semi-Lagrangian
Direct Trans.
Inverse Trans.
Grid Point Computation
Spectral Computation
A
B
C
D
E
THREAD 1.1.1
THREAD 1.9.1
THREAD 1.17.1
THREAD 1.25.1
THREAD 1.33.1
THREAD 1.41.1
THREAD 1.49.1
THREAD 1.57.1
THREAD 1.65.1
THREAD 1.73.1
THREAD 1.81.1
THREAD 1.89.1
THREAD 1.97.1
0 us
6,251,343 us


A
B
C
D
E
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.2
Instructions_DP
Instructions_SP
Cycles per Ins_DP
Cycles per Ins_SP
L3_MISS_RATIO_DP
L3_MISS_RATIO_SP
Useful Duration_DP
Useful Duration_SP